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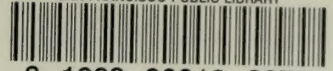
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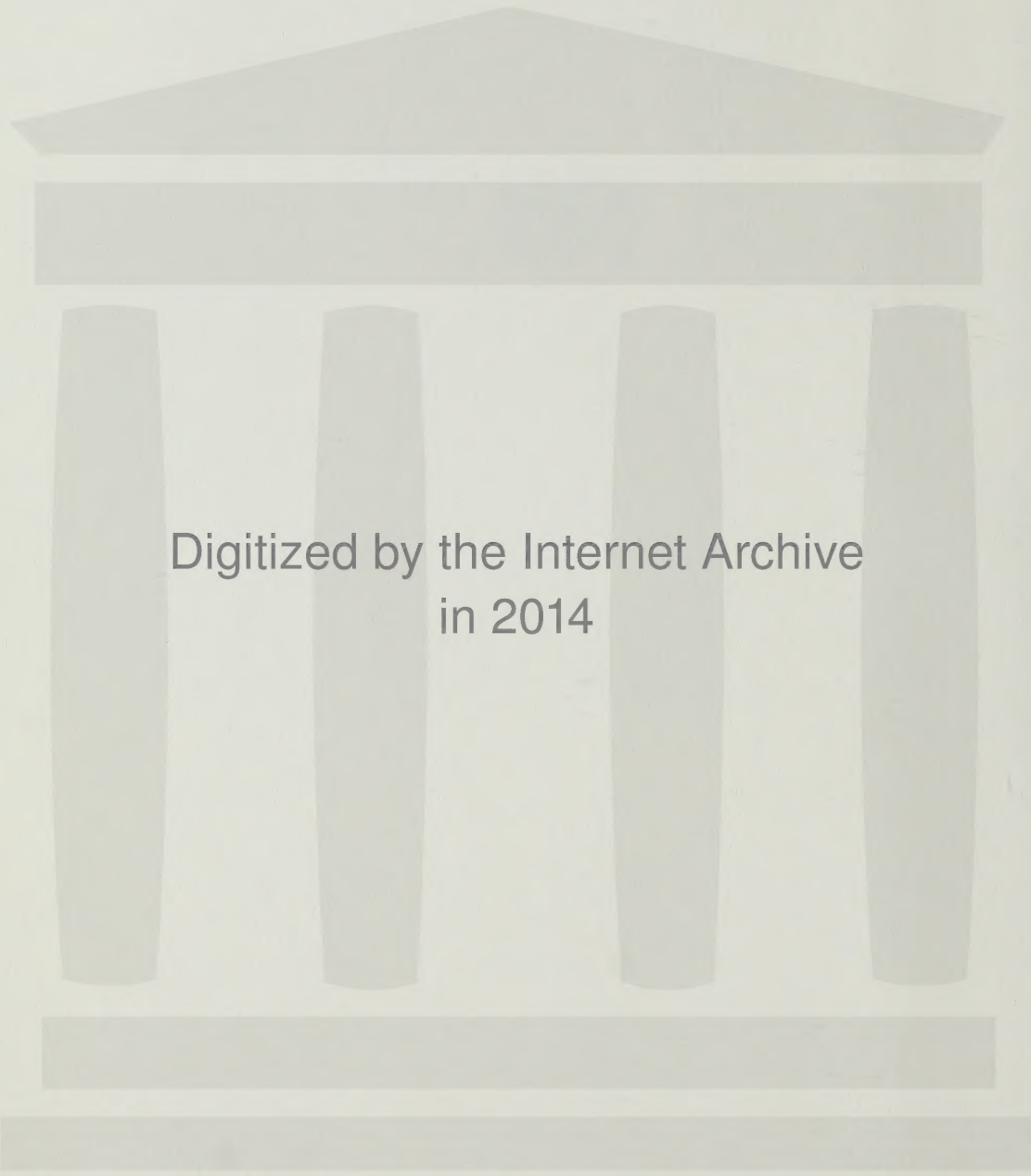
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APPENDIX B

DISSOLVED AIR FLOTATION

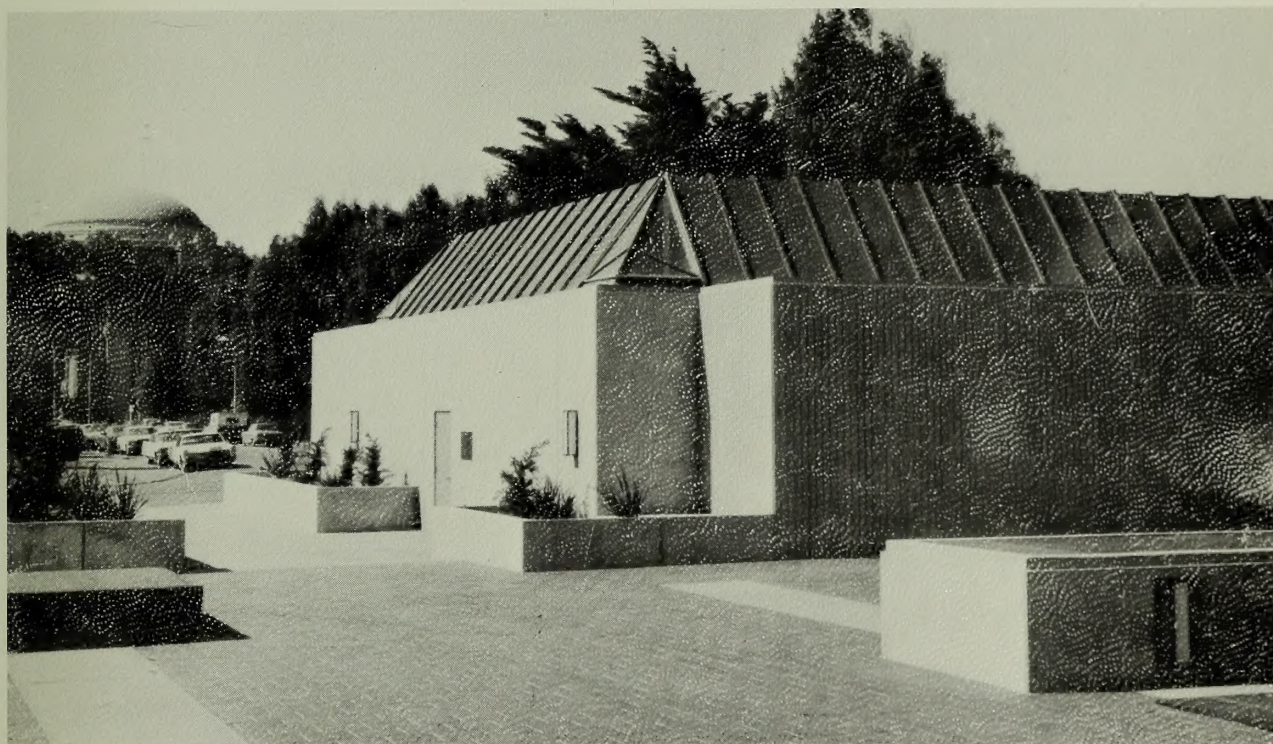
TECHNICAL OBJECTIVES FOR FIELD DEMONSTRATION OF
BAKER STREET DISSOLVED AIR FLOTATION FACILITY

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MASTER PLAN STUDY FOR WET WEATHER CONTROL PROGRAM

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DISSOLVED AIR FLOTATION

APPENDIX B

TECHNICAL OBJECTIVES FOR FIELD DEMONSTRATION OF BAKER STREET DISSOLVED AIR FLOTATION FACILITY

Part of City and County of San Francisco's
Master Plan Study for Wet Weather Control Program

submitted by

City and County of San Francisco, California

prepared by

Engineering-Science, Inc.
Research and Development Laboratory/Berkeley

for

Environmental Protection Agency
Water Quality Office

July 1971

FOREWORD

This volume constitutes the second of seven technical appendices to the Project Report on Treatment of Combined Sewer Overflows by the Dissolved Air Flotation Process. Appendices in this series are:

- A. Phase I - Pre-Construction Studies on Quality and Quantity Relationships of Combined Sewage Flows and Receiving Water Studies at Outer Marina Beach
- B. Technical Objectives for Field Demonstration of Baker Street Dissolved Air Flotation Facility
- C. Treatment of Raw and Dilute Raw Sewage with the Dissolved Air Flotation Process - A Pilot Plant Study
- D. Design Factors for Baker Street Dissolved Air Flotation Facility
- E. Costs for Dissolved Air Flotation Facilities
- F. Characterization of the Receiving Water and Beach Intertidal Zone Environment
- G. Performance Evaluation of Baker Street Facility with Raw Sewage

Appendix B is submitted in partial fulfillment of DPW Order No. 80,480 between the City and County of San Francisco and Engineering-Science, Inc., and was supported in part by Grant WPRD-258-01-68 between the Environmental Protection Agency, Water Quality Office, and the City and County of San Francisco, Department of Public Works.

This report, prepared in limited edition for utilization in City and County of San Francisco's Master Plan study for wet-weather control, is under review for approval by the Environmental Protection Agency, Water Quality Office.

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CHAPTER I

INTRODUCTION

As delineated in the original demonstration grant, the general objective of the Phase III program was to provide an operational evaluation of the dissolved air flotation process and to document the impact of the Baker Street dissolved air flotation facility on receiving water quality, permitting the development of generalized criteria for utility of the process in other areas of San Francisco and elsewhere.

This report summarizes information of specific relevance to the characterization of the dissolved air flotation process, particularly as it is applied to the Baker Street facility. The report does not cover any information developed in the course of establishing the technical objectives for the surveys for the receiving water and littoral zone characteristics; this information is presented in another appendix.

OBJECTIVES

The objectives of this study are:

- (1) To identify the key relationships describing the mechanisms and subprocesses operative in the dissolved air flotation process.
- (2) To establish objectives for how the dissolved air flotation process should be operated to illuminate process behavior.
- (3) To define the operational alternatives and capabilities of the dissolved air flotation facility at Baker Street.
- (4) To define and document the data requirements for the demonstration program.
- (5) To define the methods and procedures for data collection and reduction.

In the development of these objectives, the study has used both published information and laboratory inquiry to establish the basic premises upon which operating objectives for the field program have been developed.

ACKNOWLEDGMENTS

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The assistance of Messrs. Robert Levy, City Engineer, A.O. Friedland, Chief of the Division of Sanitary Engineering, Bureau of Engineering, and R.T. Cockburn, Project Officer, of the City and County of San Francisco is gratefully acknowledged.

CHAPTER II

OVERVIEW OF THE DISSOLVED AIR FLOTATION PROCESS

DESCRIPTION

Flotation

Flotation is a unit operation for the separation of liquid phases or for the separation of a solid phase from a liquid phase. The flotation process entails the formation of air bubble-particulate aggregates which are of lesser density than the suspending medium and which can be separated gravimetrically from the medium. The solids which are removed may be discrete or flocculent and will vary in size from colloidal to coarse suspended particles. Key elements of the flotation process are: (1) introduction of air into the liquid stream, (2) formation of minute bubbles, (3) formation of air-discrete solid aggregates, and (4) separation of the aggregates from the water.

An initial distinction between types of flotation processes can be made on the basis of the method of air introduction to the liquid stream and of bubble formation. In *dispersed air* flotation, which has been applied extensively in the metallurgical industry, gas bubbles are generated by mechanical shear of propellers, diffusion of gas through porous media, or homogenization of the gas and liquid streams. In *dissolved air* flotation gas bubbles are generated by the precipitation of air from a supersaturated solution. Dissolved air flotation can be further classified into *pressure* flotation and *vacuum* flotation depending on the pressure used to cause gas precipitation. The solution of gas under elevated pressure and its subsequent precipitation from solution at atmospheric conditions constitutes pressure flotation. Vacuum flotation involves gas solution under atmospheric pressure and gas dissolution under vacuum. Because the Baker Street dissolved air flotation plant is a pressure flotation system, subsequent discussion in this report refers only to the pressure flotation aspects of the dissolved air flotation process, or simply to the dissolved air flotation process. A flow sheet for the dissolved air flotation process is shown in Figure II-1.

Dissolved Air Flotation Process

The dissolved air flotation process, as used in the Baker Street facility,

TABLE II-1

INFORMATION REQUIREMENTS FOR SUBPROCESS
INTERACTIONS IN DISSOLVED AIR FLOTATION PROCESS

Subprocess	Information Requirements
Turbulence & mechanical-induced Mixing	Reynolds No. profiles through conduit system (influent and recycle); impact of mixing available on floc formation
Chemical addition	Wastewater quality; influent solids throughput rate; chemical dosage criteria
Air pressurization	Inlet pressure; temperature; efficiency of dissolution; recycle flow rate; influent wastewater throughput rate; influent solids throughput rate
Air bubble-particle aggregate formation	Gas stability, bubble size and number/volume, rate of bubble formation, physio-chemical environment; presence of floc; terminal rise velocity
Turbulence-induced shear	Reynolds No. profiles through conduit system (influent and recycle); floc strength
Effective aggregate formation	Aggregate strength; adhesion efficiency
Tank hydrodynamic stability	Mean, median, and model hydraulic residence time over variant rates of change of surface hydraulic loading rates
Float formation	Solids surface loading rate; solids concentration; viscosity; temperature
Float attrition	Float skimming height; float detention time; hydrodynamic stability of tank

can be considered functionally as a sequence of interacting subprocesses which serve to convert, transfer, separate, or dispose of the solids in a liquid stream. The subprocesses and subprocess interactions in the dissolved air flotation process are shown in Figure II-2.

The subprocesses of the dissolved air flotation process can be categorized as associated with the air, liquid, or solid phases or combinations thereof. Chemical addition serves to effect destabilization of colloidal particles and to aid in the formation of air-solids aggregates. Air pressurization is done by the injection of air into the suction side of a centrifugal pump and the turbulence of the flow in the piping system and the mechanical shear of the centrifugal pumps serve to implement the mixing and contact of air, chemicals, and solids in the process.

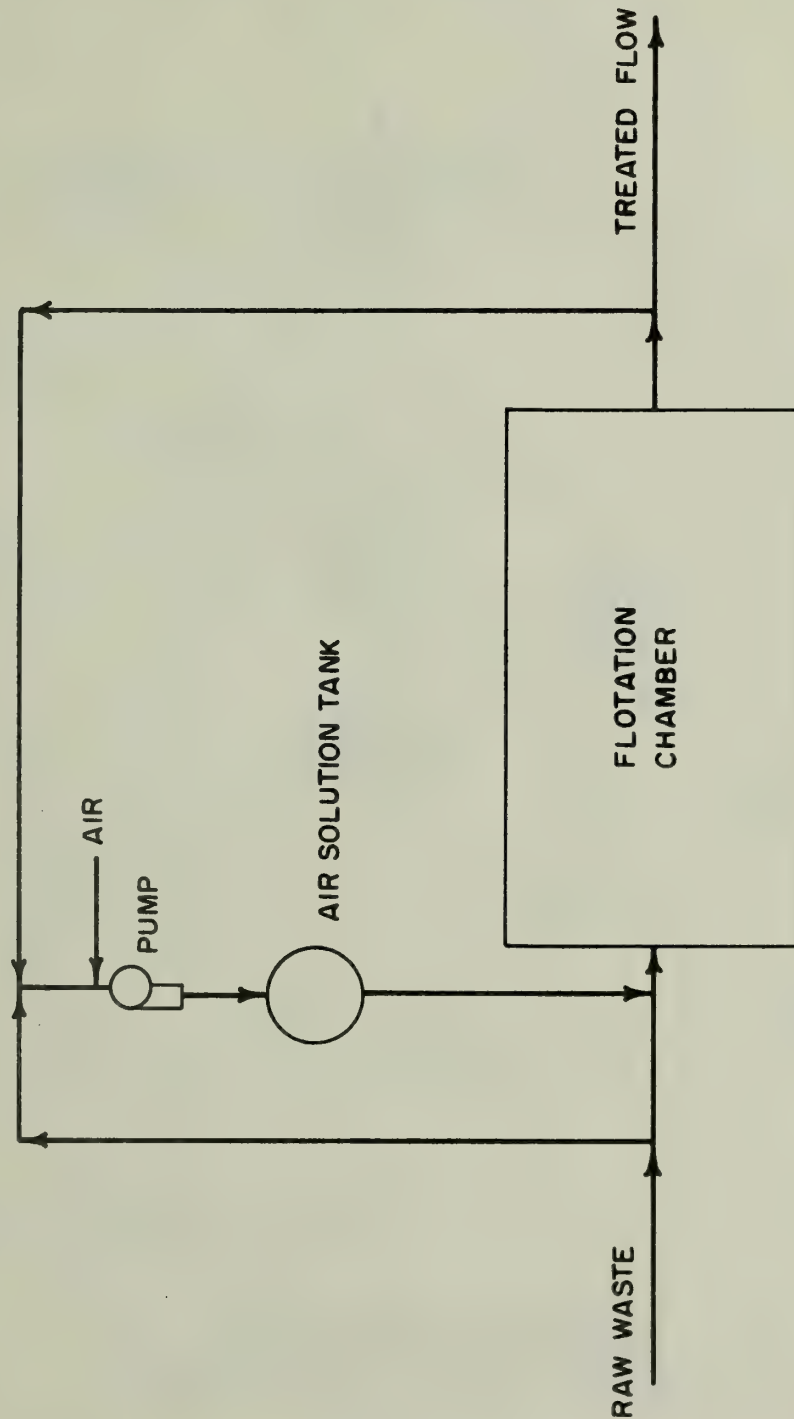
An outline of the types of information required to characterize each subprocess is presented in Table II-1. The subprocesses of the dissolved air flotation process are characterized in detail in Chapter III and the physio-chemical mechanisms associated with the process are described in Appendix A.

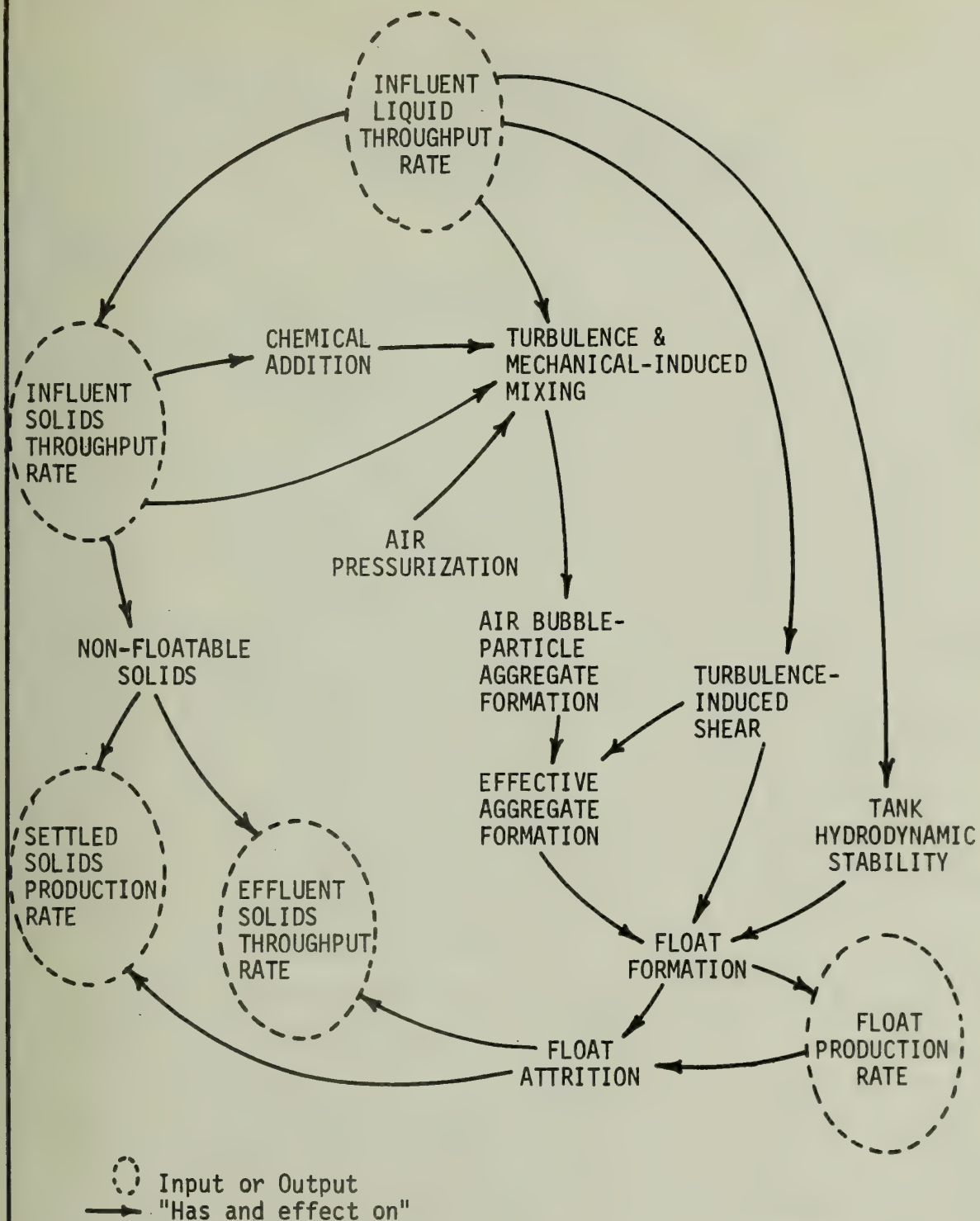
APPLICATIONS

The flotation process in its various forms has been used widely for over 60 years in the mining and mineral processing industries. The dissolved air flotation process has been used in sanitary engineering application for several decades, particularly for the thickening of primary and biological sludges in municipal treatment facilities. Industrial applications of the dissolved air flotation process have been made for the treatment of cannery wastes, laundry wastes, meat-product wastes, metal finishing wastes, and wastes from the oil, pulp and paper, soap manufacturing, and sulfur refining industries.

The application of the dissolved air flotation process to the treatment of raw domestic or combined sewage has taken place only in the last decade. To date there exists a dearth of data on the effectiveness of the dissolved air flotation process for any of its sanitary engineering applications, not to mention the application of concern with respect to the Baker Street facility.

FLOW SHEET FOR DISSOLVED AIR FLOTATION PROCESS





SUBPROCESS INTERACTIONS IN
DISSOLVED AIR FLOTATION PROCESS

CHAPTER III
CHARACTERISTICS AND PERFORMANCE OF
DISSOLVED AIR FLOTATION PROCESS

INTRODUCTION

The traditional basic objective for the sanitary engineering application of the dissolved air flotation process has been to maximize the recovery of input solids as floated and settled solids, *i.e.*, to maximize the removal of influent solids. A corollary objective in the application of the dissolved air flotation process for treatment of raw sewage, primary effluents, and combined sewage flows (yet to be demonstrated) has been to maximize the selective recovery of floatable, or potentially floatable, materials. The fundamental aspects of the dissolved air flotation process, which can be manipulated to attain these objectives, are the independent process variables associated with the input and precipitation of air, chemical addition, and solids and liquid loading (or throughput) rates. The fundamental subprocess interactions and mechanisms operative in the dissolved air flotation process are described in the previous chapter and in Appendix A. The following discussion is for the purpose of illuminating the relationships which define the subprocess interactions explicitly or implicitly, and to provide a base of information for establishing operating procedures for the dissolved air flotation facility at Baker Street (and a pilot plant, if it becomes available) to demonstrate the behavior of the dissolved air flotation process.

It has been necessary in the present chapter to draw upon the limited body of available information on the dissolved air flotation process. Inasmuch as much of the information required for design of the dissolved air flotation process is proprietary, the designer and researcher both have had little alternative but to rely on the manufacturer. As a result, there exists no generally available body of information which defines the general criteria needed by the designer. Thus, there is very little useful information available to permit the examination of the impact of the fundamental relationships (air, chemicals, and loadings) on process performance.

CHARACTERIZATION

Introduction of Air

The dissolved air flotation process is dependent upon gas dissolution into the liquid phase which, in the absence of interaction between the gas molecules and the solvent phase, can be described by Henry's Law over the range of pressures and wastewater temperatures of concern. The Henry's Law relationship can be expressed as:

$$X^G = KP \quad (III-1)$$

where: X^G = concentration of gas in solution (cc/liter)

K = Henry's Law constant (cc/liter-atm)

P = absolute pressure above the solution at equilibrium (atm)

The Henry's Law Constant is a function of the type of gas, temperature, chemical constituents in the liquid, and the system in which the gas is transferred. The variation of K with temperature for air is shown in Figure III-1. Because there exists no evidence in the literature to the contrary, it has been assumed in the present study that the Henry's Law constant for pure water can be used for the wastewaters to be treated at the Baker Street facility.

With the Henry's Law relationship as a perspective, air introduction in the dissolved air flotation process has generally been accomplished at the suction side of a centrifugal pump. Vrablik (Reference 1) has reported that from four to eight percent of the pressurized flow by volume of air can be supplied by this mode of addition to effect flotation, resulting in a 60 to 80 percent saturation of the pressurized stream with air. From 80 to 110 percent of the air required for saturation can be added to the suction side of a centrifugal pump without air binding. In pressurization systems with retention tanks of 30- to 60-sec hydraulic residence times, Vrablik reports that from 35 to 50 percent of the air added can ultimately be dissolved in the pressurized stream.

Formation of Air Bubble-Particle Aggregates

Within a general context of bubble technology, the formation of air



bubble-particle aggregates can be viewed as a sequence of events including pressure release, chemical conditioning of solids, and aggregate formation.

Pressure Release

The gas precipitated as fine bubbles of less than 100-micron diameter is the driving force for the flotation of particles whose density is greater than that of the suspending liquid. The bulk density of the aggregate formed by the attachment to, or inclusion of, air bubbles in the solid flocs must be less than the bulk density of the liquid for flotation of the aggregate to occur.

The precipitation of dissolved gas proceeds in two phases: nuclei formation and growth of nuclei (as discussed in Appendix A). The formation of nuclei can be controlled by regulating the rate of gas release, which determines the amount of shear effected at the point of release. The size of bubbles formed is a function of the method of nuclei formation. Use of higher pressures (greater than 50 psi) has been related with the generation of more even distributions of air bubble sizes (Reference 1).

Ettelt (Reference 2) has noted that bubble formation following gas release can take place in two steps in the flotation tank:

(1) Zone 1, in which the release of bubbles is marked by an accelerated motion of the bubbles.

(2) Zone 2, in which the bubbles have attained a uniform motion throughout the liquid.

The hydraulic residence time required to permit the transition from Zone 1 to Zone 2 depends on the influent flow regime as characterized by the Reynolds Number, and is ultimately a function of the liquid loading rate parameter (discussed subsequently).

Chemical Conditioning

The mineral processing industry has developed a large base of experience on chemical addition in the dissolved air flotation process which provides background for specific sanitary engineering applications of the process. In mineral processing several different kinds of chemicals have been used specifically to adjust the surface properties of mineral particles. In the selective flotation of minerals, it is essential to use

a specific type of chemical to effect the flotation of the desired mineral. Four groups of chemicals have acquired a permanent place in flotation technology according to their functions in flotation:

(1) A *frother* is a chemical which builds a froth that serves as the buoyant and stable medium in the separation of the floatable material from the liquid phase. Some of the common frothing agents are amyl to octyl alcohols, pine oil, and cresylic acid.

(2) A *collector* is a substance which enables particles to be held at the air-liquid interface. Some of the common collectors for metallic flotation are zanthates and thiocarbonilides. Soaps, fatty acids, and amines are commonly used for nonmetallic minerals such as phosphate and quartz.

(3) An *activator* induces the flotation of particles which normally do not respond to the action of collectors alone. The metallic salts are typical activators.

(4) A *depressant* is generally an inorganic substance which when added to a solution prevents temporarily or permanently the flotation of some undesirable phases without interfering with the flotation of the desired phases. Some of the common depressants are lime, sodium sulfite, cyanide, dichromate, starch, and glue.

The application of chemical flocculating agents to promote formation of flocs and air bubble-particle aggregates in flotation has been cited frequently in the sanitary engineering literature as a fundamental requirement for improved process performance. Chemicals such as alum, ferric chloride, and polyelectrolytes either singly or in combination have been used. Ettelt (Reference 2) reports the successful use of the polyelectrolyte Purifloc 601 at dosages of 0.0065 to 0.01 lb/lb activated sludge in a flotator operated for thickening at Chicago. The addition of 60 ppm of DP 243 (heteropolar lauryl amine hydrochloride) to sewage resulted in BOD removal of over 80 percent in a laboratory-scale facility (Reference 3).

The Baker Street facility is equipped to supply either polyelectrolyte alone or polyelectrolyte in conjunction with alum and caustic soda to enhance process performance. The results of a laboratory evaluation to

determine dosage criteria for the use of these chemicals at the Baker Street facility are presented in Chapter V.

Aggregate Formation

The quantification of the size, number, and character of air bubble-particle aggregates formed in a dissolved air flotation process application cannot be accomplished at the present state-of-the-art. In the absence of an explicit parameter, the air:solids mass ratio (A/S) has been used as an implicit parameter to define a relative driving force on the aggregate for flotation. Two types of A/S ratios can be defined:

(1) An input A/S ratio, $(A/S)_I$, or the ratio of mass of air added to the mass of solids loaded to the system.

(2) An effective A/S ratio, $(A/S)_E$, or the ratio of the mass of air remaining in the aggregate to the mass of solids loaded to the system after the aggregate is transported from the point of formation to the point in the flotator where quiescent flotation can commence. Ettelt (Reference 2) has defined the adhesion efficiency, A_E , as the percent ratio of $(A/S)_E$ to $(A/S)_I$. The adhesion efficiency can also be defined as the percentage of total air present that successfully adheres to the solids, and is a factor sensitive to the dynamic conditions in the system which result in the attrition of air bubble-particle aggregates. The $(A/S)_I$ is a factor which can be measured definitively in a dissolved air flotation process application, provided that an accounting can be made of the reject air from the pressurization system, which as Vrablik noted, may be from 50 to 65 percent of the air input. The $(A/S)_E$ parameter has not been quantified in dissolved air flotation experience because of the inherent difficulties of obtaining and preserving samples from the inlet sectors of flotation tanks. That is, the adhesion efficiency parameter, A_E , cannot be quantified to any extent at the present state of technology, and remains the least definable parameter in the evaluation and design of the dissolved air flotation process for specific applications.

The input air:solids ratio, $(A/S)_I$, can be calculated from the following equation, which is based on both air and solids balances (Reference 4):

$$(A/S)_1 = \frac{kX^A (fP - 1) R}{QX_0^S + RX_R^S} \quad (III-2)$$

- where: k = conversion factor, 1.28×10^{-6} lb air - liter H_2O -
 mg/l total suspended solids per cc air - lb H_2O , at
 standard temperature ($0^\circ C$) and pressure (760 mm Hg)
 X^A = concentration of air in solution at a pressure of 1 atm
 = 18.7 cc/liter/atm at $20^\circ C$ (Figure III-1)
 f = percent air saturation achieved in the retention tank
 (typically 0.35 to 0.50)
 P = pressure (atm)
 R = recycle flow rate (mgd)
 Q = influent flow rate (mgd)
 X_0^S = influent suspended solids concentration (mg/l)
 X_R^S = recycle suspended solids concentration (mg/l)

The ratio R/Q is known as the recycle ratio.

Loading Rates

Solids Loading Rate

The total suspended solids rate (lb/sq ft-day), hereafter called the solids loading rate, is one of the primary independent variables in the dissolved air flotation process, taking precedence over the liquid (surface) loading rate (gpd/sq ft) in essentially all dissolved air flotation applications as the parameter governing the surface area required for the flotation tank. The solids loading rate is the measure of the burden placed on the flotator and is a basic factor in determining the air input and chemical addition requirements for successful flotation. The one case in which the liquid loading rate takes precedence over the solids loading rate occurs when, for a given solids loading rate and influent solids concentration in a wastewater, the required liquid throughput rate is at such a level that flow velocities and turbulence and the resultant rate of destruction of air bubble-particle aggregates and float adversely affect the recovery of floated and settleable solids in the process.

Basic evidence that the solids loading parameter is a governing factor in flotator design, or more generally, a unifying concept around which the application of dissolved air flotation can be considered, is presented in Table III-1. In advancing this argument it is realized that the water volume:air volume:solids volume ratio, or ratios, may well be very significant if they could be appropriately measured. Table III-1 is a listing of available information on solids and liquid loading rates and solids recovery efficiencies observed for dissolved air flotation applications with combined sewage, primary effluents, and thickening of primary sludges and mixtures of primary and waste activated sludges. The solids loading rates varied within the range of 4 to 32 lb/sq ft-day for the dilute streams (<500 mg/l feed solids concentration) to 4 to 50 lb/sq ft-day for the sludge thickening applications. Essentially all of the reported applications used a common range of solids loading rates varying from 4 to 20 lb/sq ft-day. However, within this common range of solids loading rates, the liquid loading rates of the applications varied inversely as the feed solids concentrations, ranging between 250 to 400 gpd/sq ft for thickening and 2,000 to 12,000 gpd/sq ft for dilute streams.

The solids removal levels for the applications reported in Table III-1 reflect the ramifications of the diverse types of inlet structures, recycle schemes, and flotation tank design used in the various plants as well as actual process performance. The impact of the former two factors is discussed in subsequent sections. As a general rule the solids removal efficiency in the dilute stream dissolved air flotation applications was found to vary inversely with the solids or liquid loading rate used. The results of the pilot plant studies at Niagara Falls with raw sewage are shown in Figure III-2. The data in Figure III-2 indicate that the highest suspended solids removal rates (70 to 80 percent) were obtained with liquid loading rates of 2,000 to 4,000 gpd/sq ft (5 to 10 lb/sq ft-day) and that suspended solids removals of about 60 percent were attained at 6,000 gpd/sq ft (15 lb/sq ft-day). That these data are not representative for the general application of dissolved air flotation to dilute streams is evident from the range of total solids recovery (15 to 75 percent) reported for all the dilute stream application listed in Table III-1.

TABLE III-1
SOLID AND LIQUID LOADING RATES IN VARIOUS
APPLICATIONS OF DISSOLVED AIR FLOTATION PROCESS

Purpose of Installation	Type Solids	Solids Feed Concentrations (mg/l)	Range of Solids Loading Rates (lb/sq ft-day)	Range of Liquid Loading Rates (gpd/sq ft)	Range of Solids Recovery (%)		Reference
					@ Float	@ Total	
Combined Sewage	Sewage	110 - 180	3.6 - 18	4,000 - 12,000	-	60 - 76	5
Primary Effluent (Niagara Falls)	Sewage	200 - 500 ²	4.4 - 32	2,600 - 7,700	-	50 - 76	6
Primary Effluent (Rio de Janeiro)	Sewage	160 - 470	6.4 - 19	2,100 - 6,200	5 - 36	15 - 45	2
Thickening	Act. sl.	8,400 - 10,000	10.0 - 20	240 - 390	28 - 42	92 - 94	
Thickening	Act. sl.	1,000 - 8,000	4.0 - 21	-	-	-	7
Thickening	Act. sl.	-	10.0 - 20	-	-	-	8
Thickening	50% act. sl.; 50% primary	-	20.0 - 40	-	-	-	8

NOTES: 1 Total solids recovery is sum of floated and settled solids, where "solids" connotes total suspended solids.

2 Estimated.

Liquid Loading Rate

The liquid loading rate to the dissolved air flotation process can become a governing factor when (as noted previously) the turbulence generated by the flow of pressurized liquid through the recycle and inlet manifold systems and into the flotation tank occurs at a level which reduces the ultimate recovery of floated and settleable solids from the unit. The liquid loading rate also affects the height of flow over the effluent launders in the tank and the tank level at which the skimming system must be functional. With increasing hydraulic loading in the dissolved air flotation process, it can be expected that one or more of the following factors will become limiting relative to process performance:

- (1) Aggregate destruction in the inlet structure.
- (2) Hydraulic overloading of effluent launders and/or skimming system.
- (3) Agitation of the liquid surface in the flotator and breakup of float.
- (4) Short-circuiting.

At the mechanistic level, each of the foregoing factors has an impact on the rate of rise of the aggregate which can be attained for a given liquid loading rate and which should be attained under quiescent conditions. Laboratory flotation studies with raw sewage have indicated that maximum flotation efficiency can be realized when a completely viscous flow obtains around the aggregate, in which case Stokes' Law is applicable.

Float Development and Removal

The float (or froth) in the dissolved air flotation process is a layer of scum that builds up in the flotation tank, and is comprised of floated solid particles and collapsed or collapsing gas bubbles. The float is formed by the introduction of the pressurized waste stream into the flotation tank. Upon formation of air bubble-particle aggregates, the aggregates rise toward the liquid surface and commence to form a scum layer. The solids concentration in the float increases at a decreasing rate as the buoyant forces overcome viscous forces in the scum and thicken the scum. The final volume of the float removed is a function of the

input solids loading, the degree of thickening in the float, and the efficiency of the scum removal (skimming system). The solids in the float can be skimmed off the liquid surface by mechanical or hydraulic means. The concentration of solids in the float is a function of float skimming height and the rate of removal, and it has been noted that at slow skimming speeds the float tends to deteriorate and lose solids; that is, experience suggests that there is an optimum skimming speed dependent on the system of concern. Float skimming heights of less than one inch have been reported in several applications.

PERFORMANCE

In order to establish how a dissolved air flotation process should be operated to illuminate process behavior, it is necessary to define the relationships operative in the process and to establish their effect on process performance. With this background it is possible to define the operating objectives and data requirements to document the operative relationships in a specific dissolved air flotation application. The purpose of the present section is to assemble the available information documenting process performance as measured by floated and settleable solids recovery and as related to influent solids concentrations and loading rates, air pressurization system operation, and turbulence levels associated with liquid surface loading rates. Only one reference in the body of literature (Reference 2) provided sufficient information to document all of these relationships within the framework of a solids balance. While the information in Reference 2 is related to the thickening of activated sludge, the trends in the operative relationships defined in this application of the dissolved air flotation process have general and definitive applications for considering the performance of the Baker Street facility.

Factors Affecting Terminal Rise Rates

The rise rate of the air bubble-particle aggregates in viscous flow can be defined using Stokes' Law relationships, and can be characterized in terms of a terminal rise velocity, which is obtained when the drag and net buoyant forces on the aggregate are equal. Three factors predominantly affect the terminal rise velocity of air bubble-discrete particle aggregates,

the concentration of solids in the suspension, the $(A/S)_l$, or input air: solids ratio effecting the flotation, and the sludge volume index (SVI).

At high concentrations of particles in the suspension undergoing flotation, motion is impeded by particle collisions, resulting in hindered flotation. Ettelt (Reference 2) has evaluated the variance of terminal rise velocity with varying initial concentrations of waste activated sludge at a constant $(A/S)_l$ ratio of 0.006 and his results are shown in Figure III-3. He found that the hindered terminal rise velocity decreased gradually from approximately 0.4 cm/sec (or approximately 8,500 gpd/sq ft) at approximately 0.1 percent solids to less than 0.2 cm/sec at 0.5 percent solids. These results indicate that within the range of suspended solids levels to be handled at the Baker Street facility (<500 mg/l), hindered flotation is not expected to occur, provided that factors such as bubble size *per se* do not cause hindered flotation.

Ettelt also examined the affect of $(A/S)_l$ on hindered terminal rise velocity in the laboratory-scale flotation of 0.2 percent waste activated sludge suspensions. The results of these experiments are shown in Figure III-4. Then hindered terminal rise velocity increased by a factor of three (to 0.7 cm/sec) as the $(A/S)_l$ ratio increased four-fold from 0.01 to 0.04 lb air/lb solids. The form of the curve of Figure III-4 trends toward a saturation value of $(A/S)_l$ above which no further increase in the hindered terminal rise velocity is possible. The ramification of this trend is that a limiting, or saturation, $(A/S)_l$ exists above which either no additional air bubbles can be attached to the available surface of the particles, or the aggregate stability is affected by shear forces.

Ettelt observed different values of hindered terminal rise velocities for activated sludge having similar suspended solids concentrations and at similar $(A/S)_l$ ratios even though the size and density of the solids were similar. He attributed the divergent values to changes in the surface properties of the solids which affect the ability of an air bubble to adhere to the solid. The sludge volume index was used to assess the impact of the surface properties on the hindered terminal rise velocity, and the greatest terminal velocities were found at low sludge volume indices, *i.e.*, for sludges with the least resistance to compaction (Reference 2).

Factors Affecting Floated Solids Production

The performance of the flotation unit is closely associated with:

- (1) The $(A/S)_f$ ratio affecting the terminal velocity.
- (2) The optimum rate of recycle to maximize the $(A/S)_f$ ratio without generating undue turbulence in the system.
- (3) Inlet design for maximum adhesion efficiency.
- (4) Solids loading rate.

Ettelt has provided an extensive description of the impact of these parameters which is summarized below.

Recycle Ratio

The relationship between the recycle ratio and floated solids production in Ettelt's unit is shown in Figure III-5. A portion of the influent stream was pressurized at all times, and the $(A/S)_f$ ratio was increased by recycling part of the effluent to the feed (which consisted of approximately one percent activated sludge). With this mode of operation an increased $(A/S)_f$ ratio and partial dilution of the feed was possible. The results shown in Figure III-5 indicated that an optimum floated solids production of 6.5 lb/sq ft-day was obtained at a 40 percent recycle ratio. The initial increase in floated solids production (up to a 40 percent recycle ratio) was attributed to an increase in terminal rise velocity with the increasing $(A/S)_f$ ratio; however, it appeared that turbulence from the greater recycle volume increased at recycle ratios greater than 40 percent to the extent that a reduction in adhesion efficiency negated the positive effects on the terminal rise velocity of the aggregate effected by the increased air content and feed dilution. That is, while the theoretical relationship between $(A/S)_f$ and R defined by Equation III-2 is valid over the operating capabilities of the dissolved air flotation application, the adhesion efficiency, A_E and $(A/S)_E$, decrease rapidly with increasing recycle ratio beyond a limiting or optimal value of recycle ratio.

Input Air:Solids Ratio

The relationship between $(A/S)_f$ and floated solids production for Ettelt's



unit is shown in Figure III-6. The results presented in Figure III-6 were obtained at a constant liquid surface loading rate. The largest relative increases in floated solids production were obtained at low $(A/S)_l$ ratios where the increases in terminal rise velocities were the greatest.

Equipment limitation precluded experimentation in Ettelt's unit beyond an $(A/S)_l$ ratio of 0.018. As a result of the limitation of the $(A/S)_l$ levels attainable in the prototype, the existence of a saturation level of floated solids production as a function of $(A/S)_l$ could not be established with Ettelt's data base. Work by Vrablik (Reference 1) has indicated that the floated solids recovery will not only attain a maximum value, but will then decrease, as $(A/S)_l$ increases, particularly with flocculent-type sludges, where the greater turbulence resulting from the greater air supply may cause the partial destruction of aggregates. The implication of this trend is that an optimum $(A/S)_l$ exists (for constant recycle ratios and solid and liquid loading rates) above which no additional gain in floated solids recovery is possible with increasing $(A/S)_l$ ratios.

Inlet Design

Ettelt tested a total of six different inlet designs to ascertain the inlet design characteristics most favorable to efficient process operation. His observations with these designs were made over a range of Reynolds Numbers from 20,000 to 200,000, where the Reynolds Number definition was based on the viscosity and density of water irrespective of the air or solids content of the liquid. A 50 percent reduction in floated solids production rate was observed as the Reynolds Number increased from 20,000 to 200,000. The most efficient inlet designs were found to have the least inlet velocity profiles and the least number of abrupt changes in flow direction to effect the breakdown by turbulence of air bubble-solid aggregates.

Solids Loading

The performance of Ettelt's flotation unit was evaluated at different solids loading rates with the optimum inlet design. The results of these experiments are shown in Figure III-7, and the floated solids production at each solids loading rate is the maximum obtained by recycling. With increasing solids loading rates and turbulence, a maximum floated solids production rate was achieved at 7.4 lb/sq ft-day and a solids loading



rate of 3.5 lb/sq ft-day. Beyond this point the floated solids production decreased to less than 6 lb/sq ft-day at a solids loading rate of 10 lb/sq ft-day. The decrease in floated solids production as solids loading rates increased above the optimum level was attributed to the turbulence resulting from the increased liquid loading rates associated with increased solids loadings.

Summary

The following observations can be made from the foregoing review of the use of the dissolved air flotation process in sanitary engineering applications:

(1) Use of chemicals is a fundamental requirement in the dissolved air flotation process for attaining maximum process performance, particularly where dilute streams such as raw or primary sewage are being treated.

(2) Solids loading rate to the dissolved air flotation process is the parameter governing the required surface area, air input, and chemical addition for effective flotation up to a value of the corresponding liquid loading rate at which flow velocities and turbulence and the resultant destruction of air bubble-particle aggregates and float adversely affect the recovery of floated and settleable solids in the process. A common range of solids loading rates for sanitary engineering application of the dissolved air flotation process is 4 to 20 lb/sq ft-day.

(3) The liquid surface loading rate becomes limiting with respect to process performance in one or more of the following ways:

- (a) Aggregate destruction at the inlet structure.
- (b) Hydraulic overloading of effluent launders and/or skimming system.
- (c) Agitation of the liquid surface in the flotator and breakup of float.
- (d) Short-circuiting.

(4) The terminal rise rates of air bubble-particle aggregates in laboratory tests were found to:

- (a) Decrease with increasing solids concentration due to hindered flotation.



(b) Increase toward a maximum value with increasing input air:solids ratio $(A/S)_I$.

(c) Decrease with increasing sludge volume indices.

(5) Four relationships have been observed in prototype operation which reflect the positive impact of increasing the $(A/S)_I$ ratio and the negative impact of turbulence on dissolved air flotation process performance as measured by floated solids production. These relationships, reflecting an initial increase followed by a subsequent decrease in floated solids production, can be defined between this parameter and:

(a) Recycle ratio.

(b) Input air:solids ratio, $(A/S)_I$.

(c) Reynolds Number and flow pattern through the inlet structure.

(d) Solids loading rate.

DISSOLVED AIR FLOTATION PROCESS PERFORMANCE ON COMBINED SEWAGE OVERFLOWS

Mason (Reference 5) has presented preliminary results obtained from a demonstration screening and dissolved air flotation plant built at Milwaukee, Wisconsin for treatment of combined sewer overflows from the Hawley Road Combined Sewer. A process flow sheet for the facility is shown in Figure III-8. The design criteria used in the design of the facility are shown in Table III-2. The system was designed to treat 5 mgd of combined overflow and used fine screens (approximately 1/4-mm openings) prior to flotation.

The test facility was completed in May 1969 and the results of 30 monitored overflows were reported. The range of influent pollutant concentrations for extended overflow (> 1-hr duration at the 95 percent confidence limit) were: COD, 113 to 166 mg/l; BOD, 26 to 53 mg/l; TSS, 113 to 174 mg/l; VSS, 58 to 87 mg/l; total N, 3 to 6 mg/l; and coliforms, 1.5×10^5 to 3.1×10^7 MPN/100 ml.

The operational characteristics of the plant for the monitored storms are shown in Table III-3. The average run had a length of one to four hours. The flow rate for these runs was held constant at 5 mgd. Pressurized flow was varied in the range of 0.57 to 1.22 mgd (11 to 24 percent recycle

TABLE III-2
GENERAL DESIGN CRITERIA FOR
HAWLEY ROAD COMBINED SEWER DISSOLVED AIR FLOTATION FACILITY

Process and Criterion	Description of Criterion
<u>Screen</u>	
Raw Flow Rate	5 mgd
Hydraulic Loading	72,000 gpd/sq ft
Screen Size	50 x 50; 297-micron openings
Screen Wash	150 gpm maximum
<u>Flotation Tank</u>	
Flow Rate	5 mgd
Surface Loading	4,320 - 12,960 gpd/sq ft
Horizontal Velocity	3 fpm
Pressurized Flow Rate	0.57 - 1.57 mgd
Operating Pressure	40 - 70 psig
Minimum Particle Rise Rate	0.5 - 1.5 fpm

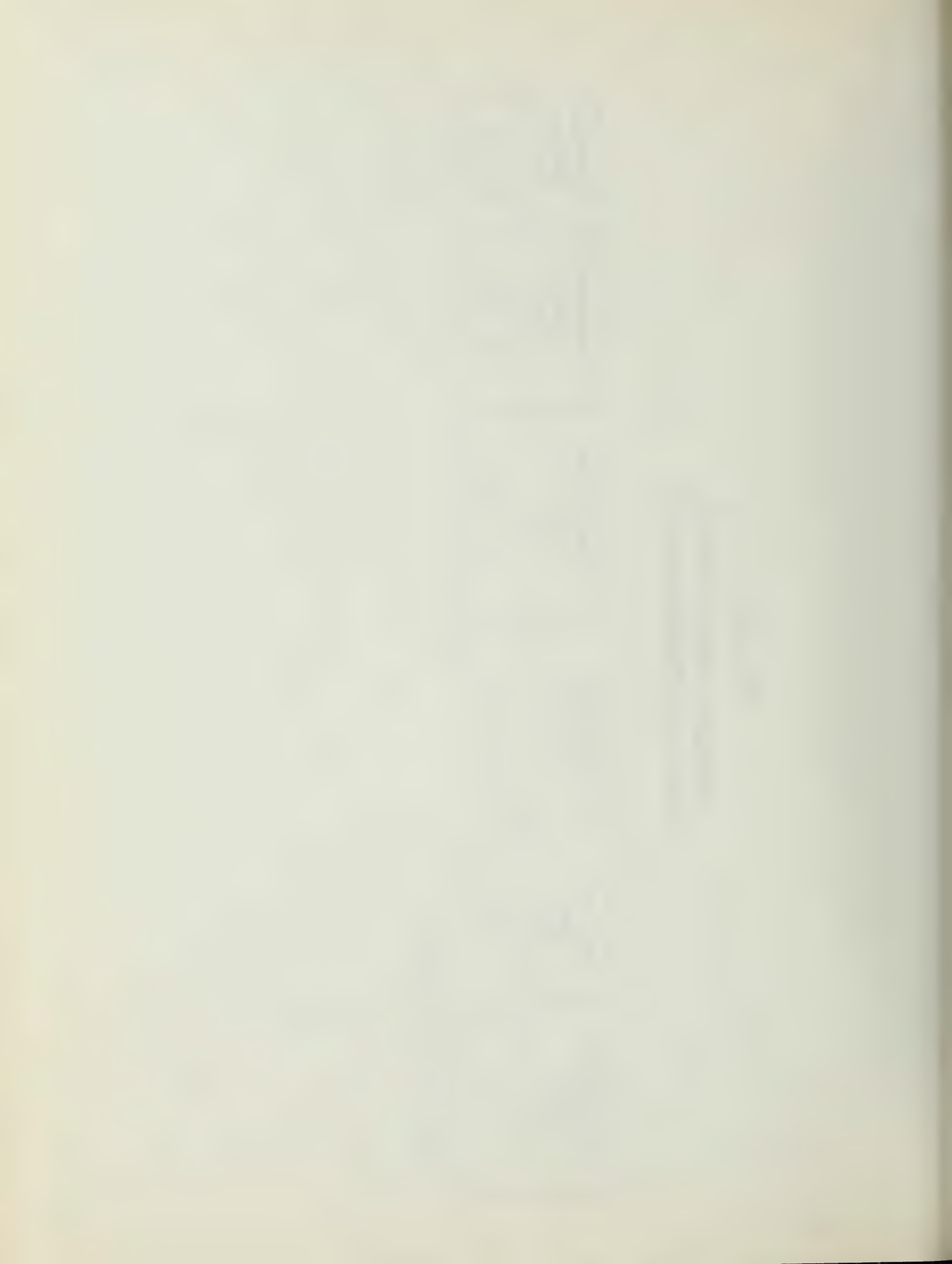
NOTE: Data from Reference 5.



TABLE III-3
OPERATIONAL CHARACTERISTICS OF
HAWLEY ROAD DEMONSTRATION FACILITY

Length of Run Hours	Raw Flow Rate (gpm)	Screen Wash as % of Flow (%)	Floated Scum as % of Flow (%)	Pressurized Flow Rate (gpm)	Operating Pressure (psig)
1 - 4	3,500	0.29 - 0.64	0.43 - 0.85	400 - 900	40 - 60

NOTE: Data from Reference 5.



ratio). The volume of water required to backwash and clean the screen varied from 0.29 to 0.64 percent of the influent flow rate, while the volume of floated scum varied from 0.43 to 0.85 percent of the influent flow rate at the 95 percent confidence level. Solids concentrations in these streams were generally in the range of one to two percent.

The performance characteristics of Hawley Road facility for 30 monitored overflows are reported in Table III-4. All runs were started with the tank full of water from the previous run, although the tank could also be operated in a near empty mode for start up. Two time periods of monitoring are shown, for spring storms and for summer and fall storms. During the spring storms, removals at the screen varied from 23 to 33 percent for all listed parameters. During the summer and fall storms, however, COD removals decreased indicating a change in the characteristics of the overflow. Removals are reported both with and without the addition of chemical flocculents. The chemical flocculents when utilized were a cationic polyelectrolyte (Dow C-31) and a flocculent aid (Calgon A-25). The polyelectrolyte dosage was 4 mg/l and the coagulant aid dosage was 8 mg/l. Contaminant removal without chemical addition was about 50 percent for all parameters as shown in Table III-4. The addition of chemical caused an increase in SS and VSS removals to around 70 percent. COD and BOD removal, however, did not increase significantly. Chemical addition was also found to provide a strengthening effect on the floated sludge blanket.

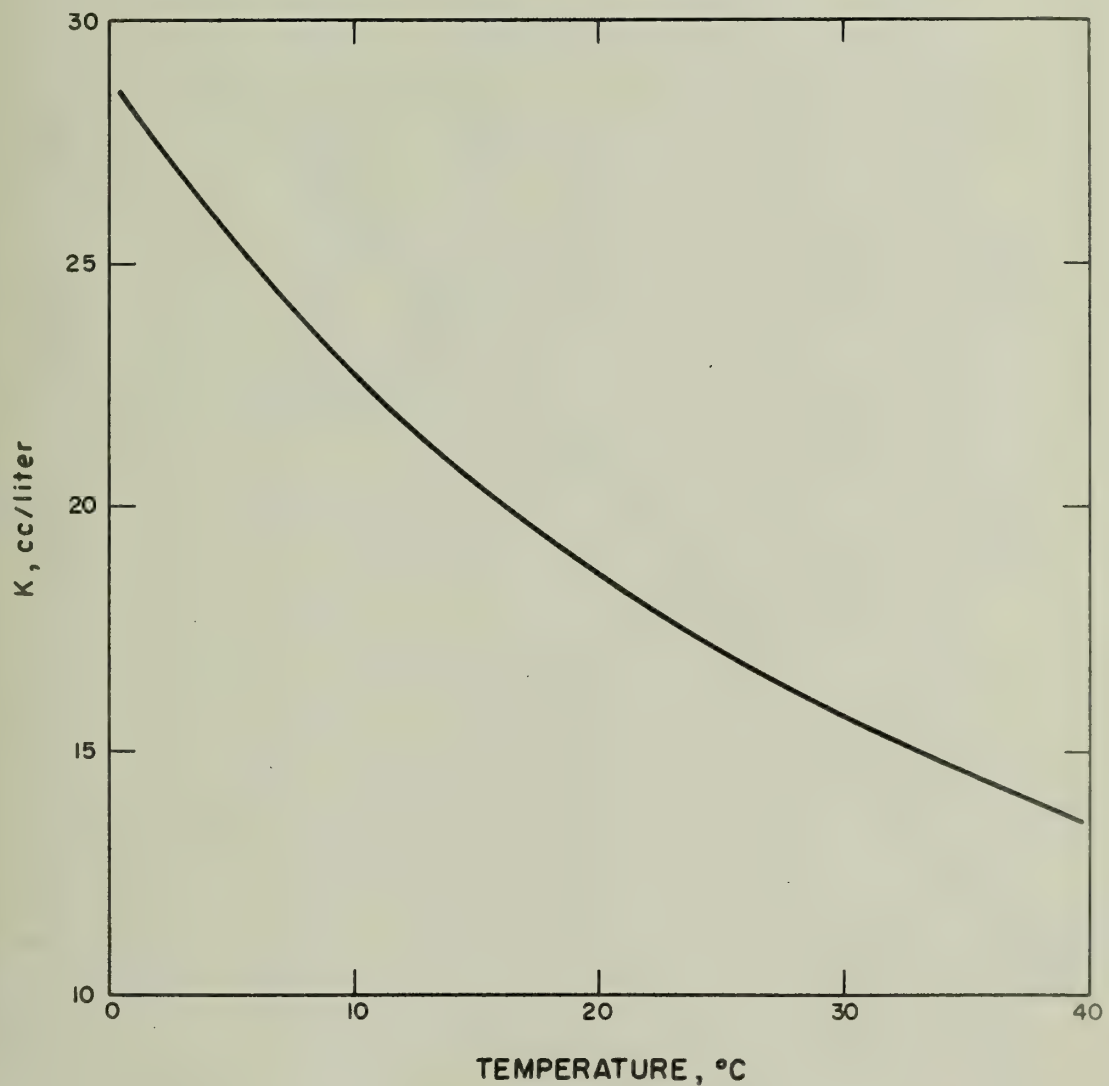


TABLE III-4
PERFORMANCE CHARACTERISTICS OF HAWLEY ROAD
DEMONSTRATION FACILITY

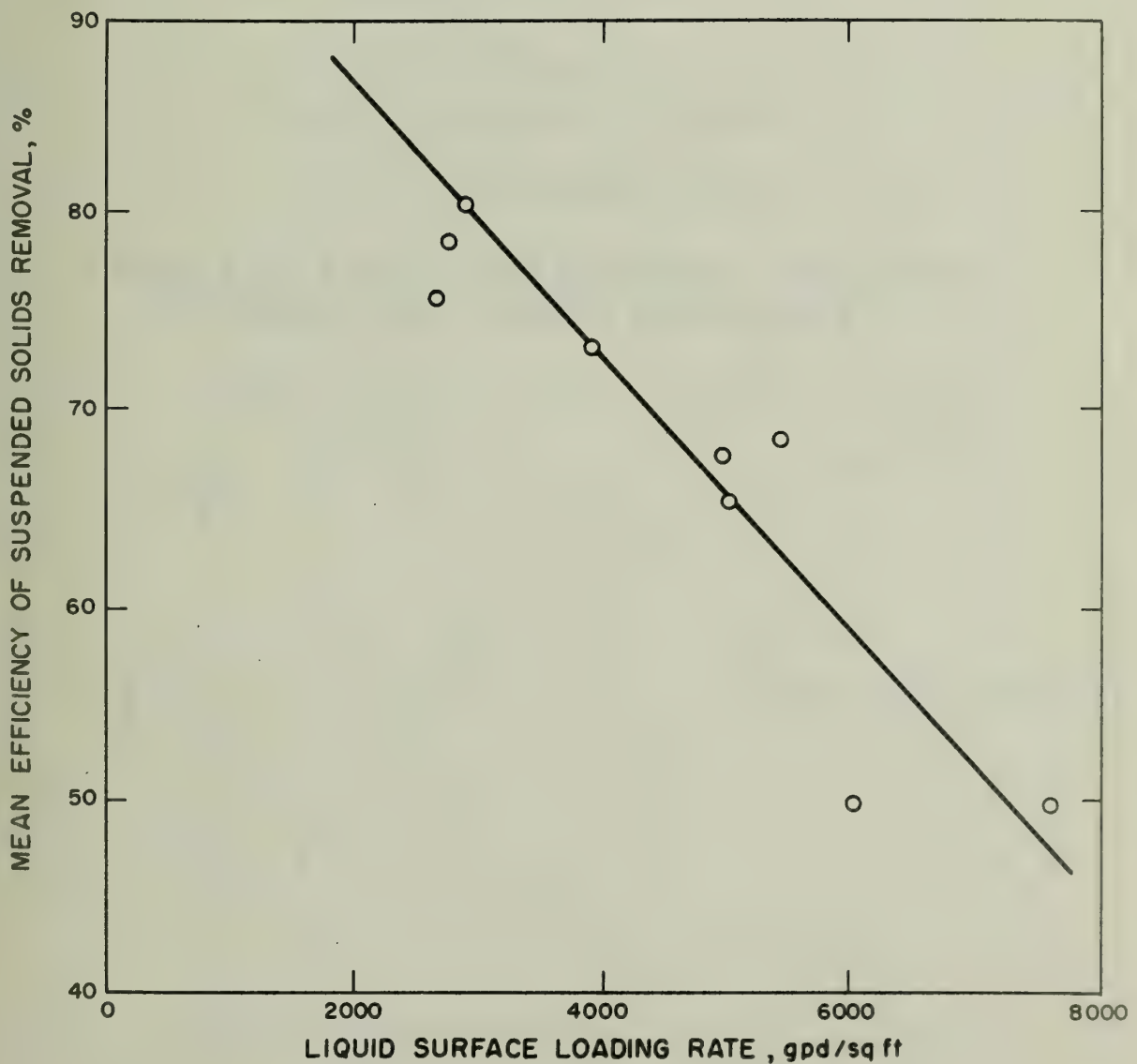
Constituent	Percent Constituent Removals			
	Screening		Screening and Flotation	
			W/O Chemical Flocculents	W/Chemicals Flocculents
	Spring	Summer-Fall	(Spring)	(Summer-Fall)
BOD	23.4 ± 9.3	20.3 ± 6.5	48.4 ± 15.7	50.8 ± 12.5
COD	33.9 ± 10.7	22.4 ± 5.0	52.9 ± 8.7	53.4 ± 8.6
SS	28.8 ± 10.5	24.9 ± 9.8	53.7 ± 11.7	68.3 ± 8.4
VSS	28.2 ± 13.6	24.4 ± 13.2	51.0 ± 15.9	64.8 ± 10.0

- NOTES: (1) Removal as % @ 95% confidence level.
 (2) Screen openings 297 microns.
 (3) Surface loading 4,300 gpd/sq ft.
 (4) Chemical Flocculents: Dow C-31; Calgon A25.

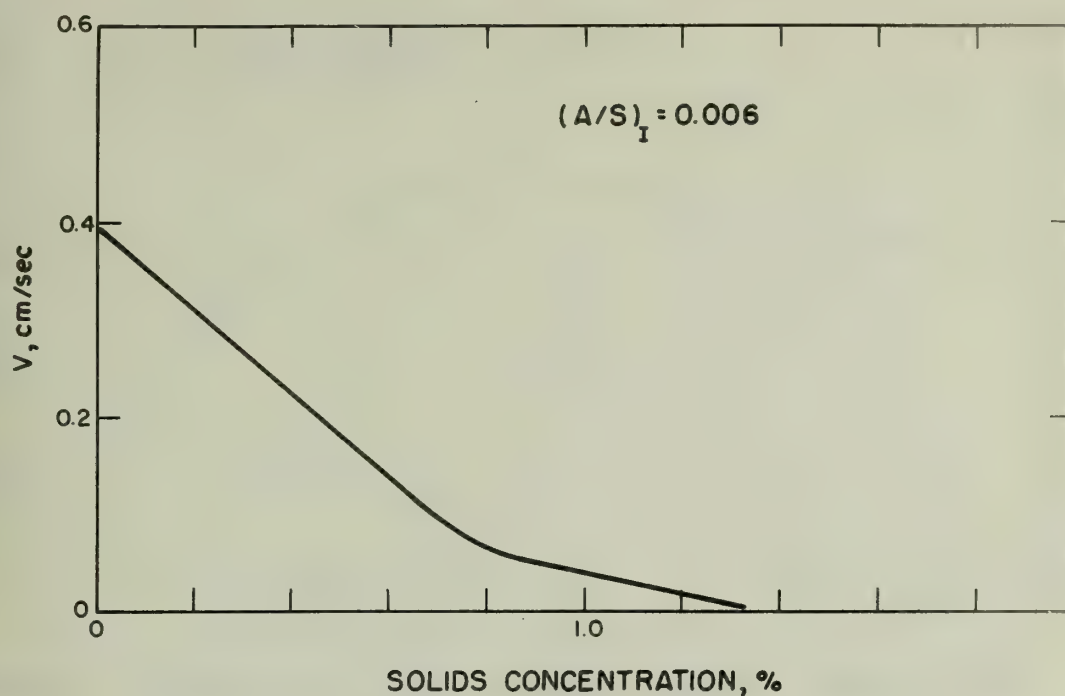
HENRY'S LAW CONSTANT
(Solubility of air in water at various temperatures at a pressure of 1 atm)



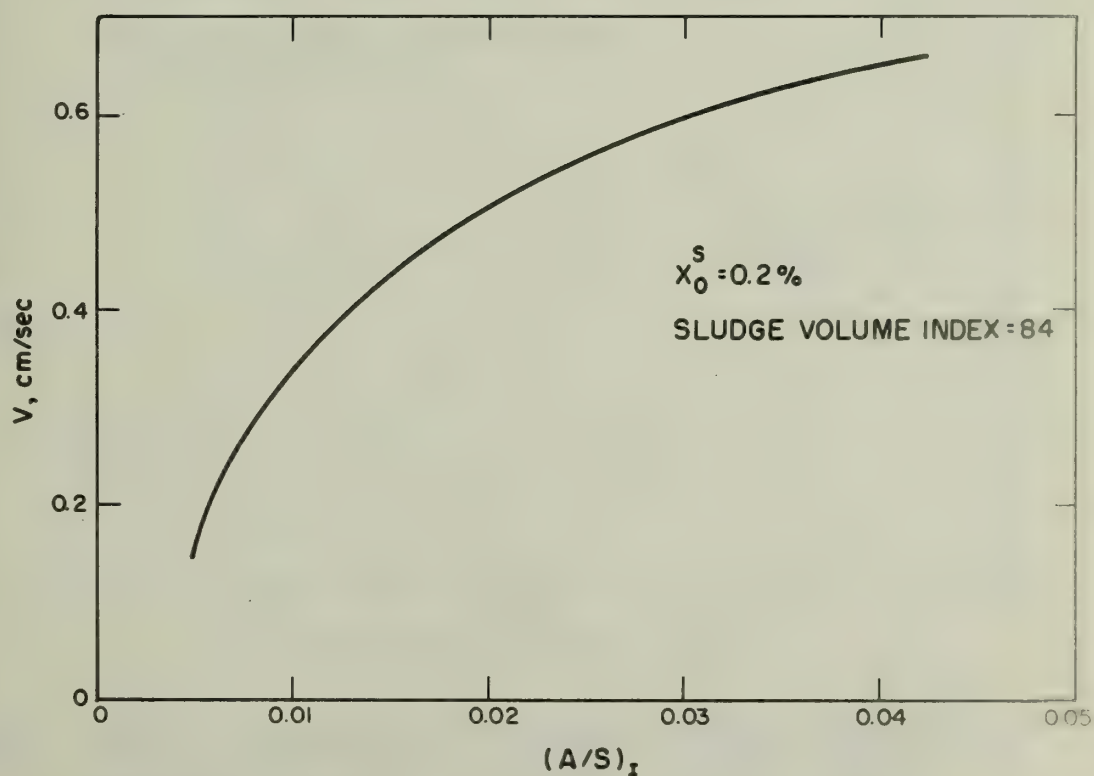
EFFECT OF LIQUID SURFACE LOADING RATE ON EFFICIENCY
OF SUSPENDED SOLIDS REMOVAL FROM RAW SEWAGE
(Pilot test data at Niagara Falls, New York; Rex Chainbelt Company)



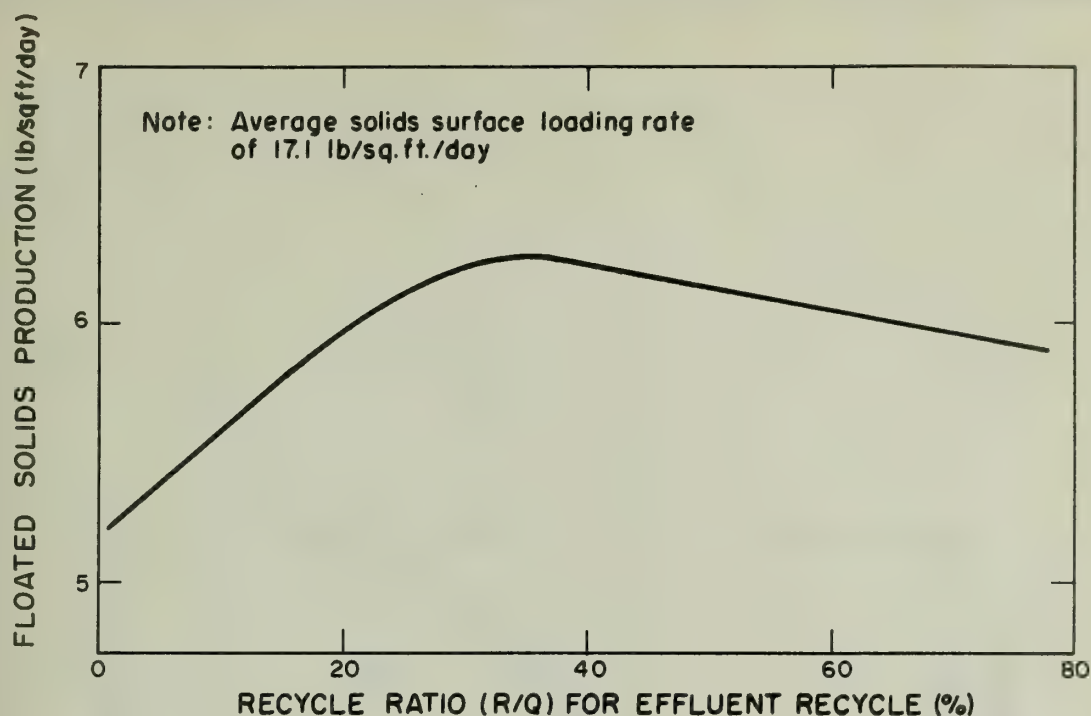




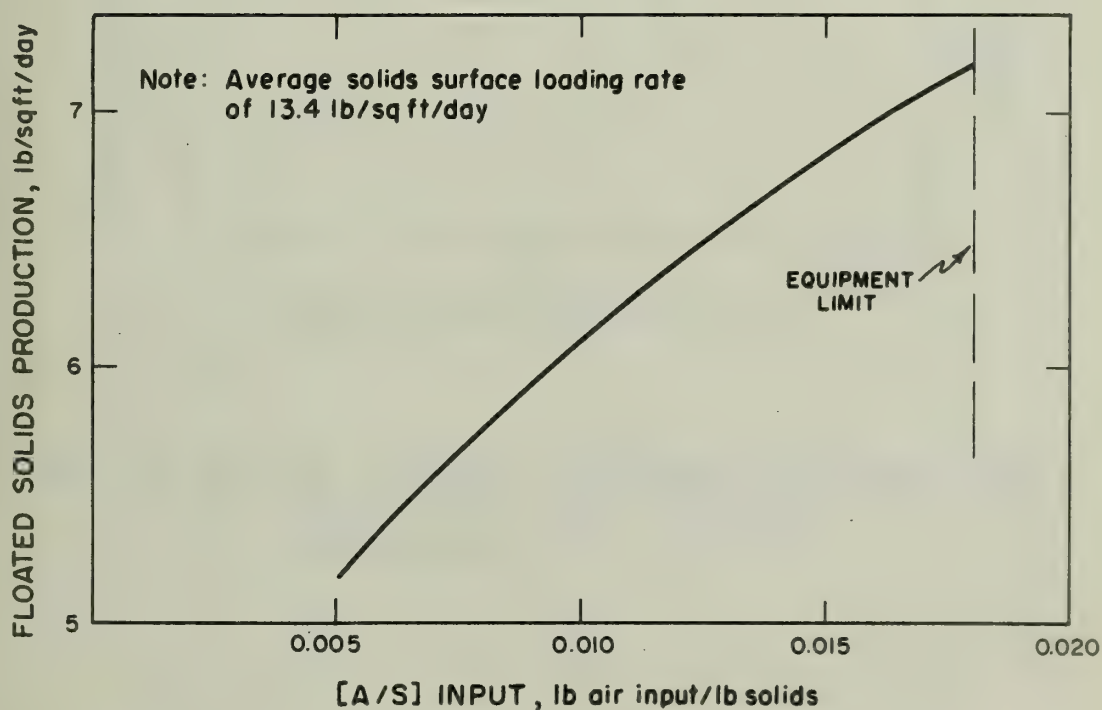
EFFECT OF SOLIDS CONCENTRATION ON HINDERED
TERMINAL RISE VELOCITY (Reference 2)



EFFECT OF A/S RATIO ON HINDERED TERMINAL RISE
VELOCITY (Reference 2)



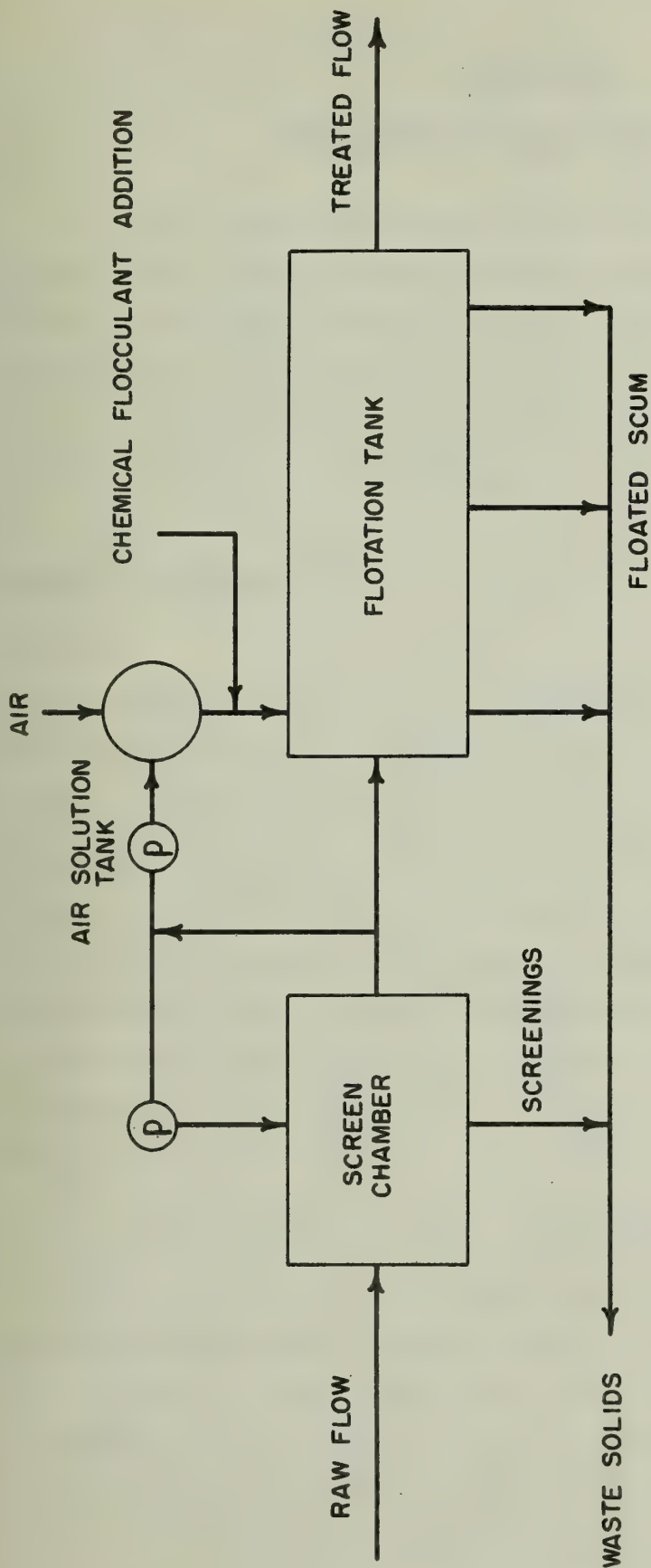
EFFECT OF RECYCLE ON FLOATED SOLIDS PRODUCTION
(Reference 2)



EFFECT OF A/S RATIO ON FLOATED SOLIDS PRODUCTION
AT CONSTANT LIQUID SURFACE LOADING RATE
(Reference 2)



EFFECT OF SOLIDS SURFACE LOADING RATE ON FLOATED
SOLIDS PRODUCTION AND RECOVERY
(Reference 2)



PROCESS FLOW SHEET FOR HAWLEY ROAD
DEMONSTRATION FACILITY, MILWAUKEE
(Reference 5)

CHAPTER IV

DESCRIPTION OF BAKER STREET FACILITY

The Baker Street dissolved air flotation facility has been described at all levels of detail in working papers, drawings, and specifications developed in the design of the facility. The intent of the present chapter is to summarize the basic information provided in these documents and to illuminate the material transfers required in a treatment operation, the features of the chemical feed system, and the critical hydraulic characteristics of the facility.

GENERAL DESCRIPTION

Location

The Baker Street facility is located at the northwest corner of the Marina Green in San Francisco. Figure IV-1 is a location map showing the facility, the 108 in. diameter outfall serving the facility, and the sewerage system immediately upstream from the plant at the intersection of Baker Street and Marina Boulevard. The Baker Street combined sewer receives the dry weather flow of a population of 14,500 people including 7,000 persons in the Presidio, and the wet weather storm runoff from the 167-acre Baker Street drainage area. The peak storm runoff rate for a five-year storm from the Baker Street drainage area is about 150 mgd.

Facility

A partial process flow sheet for the Baker Street facility is presented in Figure IV-2 and the principal characteristics and components of the facility are listed in Table IV-1. The hydraulic capacity of the entire treatment facility is 24 mgd and the capacity of the influent structure and outfall is 160 mgd, sufficient to accommodate the runoff from a five-year storm. The treatment facility is comprised of two "modules" each of 12 mgd capacity and each capable of operation independent of the other. As noted in Figure IV-2 and

TABLE IV-1

PRINCIPAL CHARACTERISTICS AND COMPONENTS OF BAKER STREET DISSOLVED AIR FLOTATION FACILITY

Sector	Item	Description
Hydraulic Flotation Cells	Treatment capacity	24 mgd total; 12 mgd per flotation tank (2) or 3 mgd per flotation cell (8)
	Influent/Effluent	160 mgd; 24 mgd treated flow and 136 mgd bypass
	Overflow rate	6,000 gpd/sq ft
	Volume	52,000 gal/cell or 210,000 gal per tank
	Detention time	25 minutes
	Weir loading rate	75,000 gpd/ft at 6,000 gpd/sq ft overflow rate
	Flight speed	2 fpm
Recycle System	Sludge removed	Screw conveyor: 5, 10, 15 rpm variable; 100 gpm maximum
	Skimmer system	Front skimming depth, 0.2 in.; back skimming depth 0-1 in.; 3/4-min skimming cycle per 0 to 30 min intervals
	Recycle pumps	One two-stage centrifugal pump per tank at 2.4 mgd each rated capacity
	Retention tank	One per tank at 150 cu ft each, or 74 sec hydraulic residence time
	Air supply	One compressor per tank rated at 26 SCFM each at 65 psi; actual available supply 10 to 13 SCFM per tank

Date	Description	Debit	Credit
1890	Jan 1	100.00	
Feb 1	200.00		200.00
Mar 1	150.00	150.00	
Apr 1	100.00		100.00
May 1	250.00	250.00	
Jun 1	180.00		180.00
Jul 1	120.00	120.00	
Aug 1	90.00		90.00
Sep 1	300.00	300.00	
Oct 1	220.00		220.00
Nov 1	160.00	160.00	
Dec 1	110.00		110.00
Total		1,510.00	1,510.00

TABLE IV-1 (Cont'd)

Sector	Item	Description
Chemical Feed System	Alum solution	36°Be, 36.5% $Al_2(SO_4)_3$
	Alum storage	One 2,700 gal tank
	Alum feed rate	One pump variable to 250 gph maximum
	Caustic solution	30% caustic, 39.9% NaOH
	Caustic storage	One 700 gal tank
	Caustic feed rate	One pump variable to 100 gph maximum
	Polyelectrolyte solution	Dow Purifloc C-31, 50,800 mg/l
	Polyelectrolyte storage	One 1,300 gal tank
	Polyelectrolyte feed rate	One pump per tank, each variable to 110 gph maximum
	Hypochlorite solution	14% available Cl_2
Solids Handling System	Hypochlorite storage	One 3,600 gal tank
	Hypochlorite feed rate	One pump per tank, each variable to 75 gph maximum
	Air lift pump	One pump per tank for transfer of settled solids to solids sump; air consumption to est. 3 SCFM maximum
	Solids sump pump	One pump variable to 550 gpm maximum

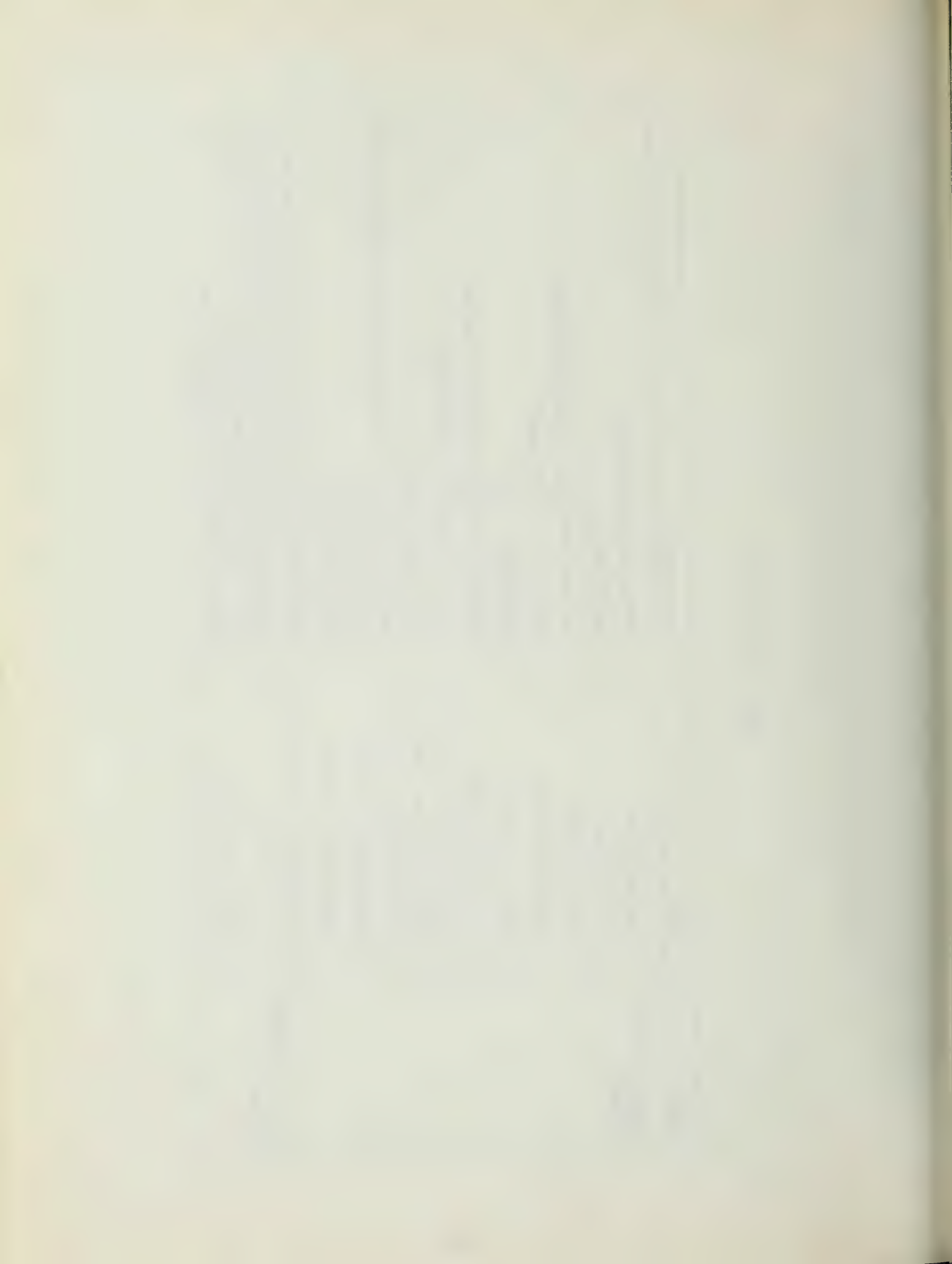


Table IV-1, each module has the following key components:

(1) Flotation tank, designed at a nominal surface loading rate of 6,000 gpd/sq ft and equipped with sludge and scum removal systems.

(2) Recycle system, with pumping capacity rated at 2.4 mgd (or 20 percent of the maximum influent flow rate), piping to permit intake of recycle flow from either the flotation tank at a point just under the effluent launder or from the raw influent stream. The recycle system includes a two stage centrifugal pump, retention tank, and four pressure reducing valves (one for each of the four flotation cells in each tank).

(3) Chemical feed systems for handling alum, caustic, polyelectrolyte, and sodium hypochlorite solutions.

(4) Solids handling system, providing for the air-lifting of settled solids and gravity flow of floated solids to a common solids sump for both modules and for the ultimate transfer of material from the solids sump to the Marina Pumping Station.

The control system of the facility provides for the fully automatic startup of the module selected for initial filling and for sequential automatic startup of the other module after a preset flow rate is attained in the first module. The details of the control system are presented in Appendix B as excerpted from the specifications in the bid documents for the facility.

MATERIAL BALANCES

A key factor in the description of the process performance is the documentation of all liquid, air, and solid transfers occurring in the facility during a selected mode of operation. The elements of material balances for liquid, air, and solids transfers to and from the flotation tanks of each module are listed in Table IV-2.

There is a total of seven elements in the liquid balance, three of which are metered (influent flow rate, chemical solution flow rates, and volumetric flow rate from the solids sump). The volumetric flow



TABLE IV-2
ELEMENTS FOR LIQUID, AIR, AND SOLIDS BALANCES
AROUND FLOTATION TANKS AT THE
BAKER STREET DISSOLVED AIR FLOTATION FACILITY

Sector	Inputs	Outflows
Liquid	1. Influent flow rates to each tank* 2. Washwater flow rates into each skimmer system. 3. Chemical solution flow rates*	1. Effluent flow rates from each tank. 2. Float volumetric flow rates from each tank. 3. Settled sludge volumetric flow rates from each tank. 4. Volumetric flow rate from solids sump**
Air	1. Air compressor output rates on each side*	1. Dissolved air flow rates in recycle stream to each tank. 2. Reject air flow rates from retention tank on each side. 3. Air lift pump air flow rates on each tank.
Solids	1. Influent mass solids flow rates to each tank. 2. Influent chemical mass flow rates.	1. Solids mass flow rates in effluent from each tank. 2. Float mass removal rates from each tank. 3. Settled sludge mass removal rates from each tank. 4. Mass solids flow rate from solids sump. 5. Screenings mass removal rate.

* Metering available in each module.

** One sump and pump system shared by both modules.

rate from the solids sump (which is common to both modules) is equal to the sum of the float and settled solids volumetric flow rates from both tanks. As a result, and if it is assumed that the wash-water flows into each skimmer system and the chemical solution feed rates are negligible inputs, then the combined effluent flow rate from both tanks can be estimated as the difference between the volumetric flow rate from the solids sump and the sum of the influent flow rates to each flotation tank. At the present time, there is no metering available on the float or settled solids streams from either tank, and the sum of float and settled solids volumetric flow rates (i.e., the volumetric flow rate from the solids sump) can be determined for one flotation tank only if one module alone is being used.

Air balances require the documentation of four elements as noted in Table IV-2. At present only one of the four elements (the air compressor output rates) on each side (west or east tank) is metered. It is estimated that from 50 to 65 percent of the air added to the recycle flow at the suction side of the two-stage centrifugal pump will not be dissolved into the flow in the retention tank and will become reject air vented from the retention tank (these percentages of reject air are equivalent to f factors of 0.35 to 0.50 in Equation III-2). The air flow rates required for operation of the air lift pumps are not known definitively, but are believed to be less than three SCFM. Because of the present lack of definity in the reject air and air lift pump flow rates, it will be possible at present to make only crude estimates of the $(A/S)_1$ ratio for operation of the facility.

There are seven solids transfer elements to be considered in making solids balances around the flotators (Table IV-2). None of the solids mass flow rates are metered directly, but three of the seven streams are metered for volumetric flow rate as discussed above. A fourth element, the screenings mass removal rate, can be measured approximately. Solids balances on the inflows and outflows from both flotators can be measured by frequent determination of solids levels



in each stream of concern, and by performing a solids balance in the format of the liquid balance described above. Because of the common solids sump for both modules, a solids balance can be performed on one module only if that module alone is being operated.

CHEMICAL FEED SYSTEM

Independent chemical feed systems, consisting of tankage, pumpage, and alternative chemical introduction points, have been provided for alum, caustic, polyelectrolyte, and sodium hypochlorite solutions. In this framework the control system provides the operator with two basic chemical addition options:

(1) Polyelectrolyte alone can be fed to both tanks.

(2) Polyelectrolyte alone can be fed to one tank and polyelectrolyte and/or alum and caustic can be fed to the other tank.

The pumping rates for the feeding of each chemical are driven off two proportionalities so that a constant dose of each chemical can be delivered over the entire flow rate range (0 to 12 mgd) of each module. The proportionalities are as follows:

(1) The delivery rate of each chemical feed pump is proportional at any time to the flow rate entering the module of concern, so that the maximum delivered dose (at 100 percent manual control settings) is always constant and determined by the stock solution titer and the maximum delivery rate of the chemical feed pump.

(2) The desired dose is selected by adjusting a manual control setting which reduces proportionally the pump output rate and, as a consequence, selects the dose that can be delivered.

Chemicals

Alum

The alum system is equipped with a 2,700-gal storage tank and a 250-gph variable-speed pump. The stock alum solution which has been specified is: 36° Be; 5.34 lb of dry material (which is 16 percent



Al_2O_3) per gallon; 365,000 mg/l $\text{Al}_2(\text{SO}_4)_3$ at 60°F. The maximum delivered dose from the alum feed system for the above solution and with complete mixing is 182 mg/l $\text{Al}_2(\text{SO}_4)_3$.

Caustic

The caustic system is equipped with a 700-gal storage tank and a 100-gph variable-speed pump. The stock caustic solution is: 30 percent NaOH; 399,200 mg/l NaOH. The maximum delivered dose from the caustic system is 79 mg/l.

Polyelectrolyte

The polyelectrolyte system is equipped with two 110-gph variable-speed pumps and a 1,300-gal storage tank. As discussed in Chapter V, Dow Purifloc C-31 was selected as the polymer to be considered; a stock solution will consist of one 55-gal drum of polymer per 1,300-gal tank, equivalent to a stock titer of 50,800 mg/l. The maximum delivered dose from each polymer pump to each module is 11 mg/l.

Sodium Hypochlorite

The sodium hypochlorite system is equipped with a 3,600-gal storage tank and two 75-gph delivery pumps. The stock hypochlorite solution is "14 percent trade solution", containing 1.17 lb available chlorine per gal. The maximum delivered dose is 22 mg/l from each hypochlorite pump.

Treated Volumes

The total volumes of wastewater that can be treated with the storage available for each chemical and at specified doses are reported in Table IV-3. At the maximum delivered doses noted for each chemical above, 5.4 M gal (million gallons) can be treated with alum, and 3.5 M gal with caustic in one module; 2.95 M gal with each polymer feed system; and 12.0 M gal with each hypochlorite feed system. If it is assumed that a typical dose situation is represented by that presented in Table IV-3, then alum storage becomes the rate limiting factor in terms of volume treated; the alum supply will be exhausted by



TABLE IV-3
TREATED VOLUMES FOR CHEMICAL STORAGE CAPACITY
AT BAKER STREET DISSOLVED AIR FLOTATION FACILITY

Chemical	Stock Solution	Operation at Capacity			Typical Dosage Situation		
		Maximum Feed Pump Capacity (gph)	Storage Capacity (gal)	Treated Volume (10 ⁶ gal @ 100% manual control setting)	Typical Dose (mg/ℓ)	Manual Control Setting (%)	Treated Volume (10 ⁶ gal) @ Typical Dosage
Alum	36.5% Al ₂ (SO ₄) ₃	250	2,700	5.40	120	67	8.1
Caustic	39.9% NaOH	100	700	3.50	21	27	12.9
Polyelectrolyte (C-31)	50,800 mg/ℓ	2 @ 110	1,300	2.95 ^a	3 ^b 6 ^c	27 55	10.8 ^a 5.4 ^a
Sodium Hypochlorite	1.17 lb available chlorine/gal	2 @ 75	3,600	12.00 ^a	20	80	15.0 ^a

^a Per pump; total treated is twice quantity shown.

^b Used in conjunction with alum and caustic.

^c Polyelectrolyte alone.



treatment of 8.1 M gal of wastewater at a delivered dose of 120 mg/l.

Chemical Introduction Points

The introduction points available for each chemical on both the recycle loop and main influent line are shown in Figure IV-3. The available points of introduction provide three options to the operator:

(1) Introduction of all four chemicals into the main influent line just downstream from the magnetic flow meter, in which case from six to eight seconds of residence time is available in the influent line before the flow enters the flotator.

(2) Introduction of caustic, alum, and polymer in the sector of the recycle loop between the suction side of the two-stage recycle pump and the upstream side of the pressure reducing valves. The residence time in this sector of the recycle loop is about 90 seconds at a 2.4-mgd recycle flow, and the recycle pump and pressure reducing valves provide a significant degree of turbulent mixing.

(3) Introduction of polymer downstream from the pressure reducing valve, in which case the residence time is less than two seconds and the inlet manifold is the vehicle by which the chemical can be mixed into the solvent stream.

With respect to alum and caustic addition, two of the above options can be considered in terms of desirability for chemical introduction, *i.e.*,

(1) Introduction at the main influent line into the total flow, with mixing of the chemicals taking place at the inlet manifold.

(2) Introduction to the recycle flow (20 percent of the influent flow) with mixing available at the recycle pump and pressure reducing valve for the recycle flow, and at the inlet manifold for the mixing together of both the recycle and influent flow streams.

Inasmuch as the added chemical cannot be used efficiently without complete mixing, it would appear that the latter option offers the most advantage in selecting points of chemical input. With respect to

floc formation, it is anticipated that the 90-sec residence time available in the recycle loop will permit the formation of primary alum flocs, but that the shear fields set up as the recycle flow is passed through the pressure reducing valves and mixed with the influent flow in the inlet manifold will preclude secondary floc formation until the floc enters the quiescent zone of the flotator.

AIR INPUT CHARACTERISTICS

Equation III-2 was used to estimate the $(A/S)_l$ rates for each module at the Baker Street facility as a function of recycle ratio and influent flow rate. The assumptions used in applying Equation III-2 were: $X_O^S = 100$ mg/l influent suspended solids; $P = 65$ psi or 4.42 atm; $f = 0.35, 0.40, 0.45, \text{ and } 0.50$; and temperature @ 20°C . The above variables represent conditions either used, or expected, with the equipment and wastewater at the facility. The computations are based on a constant recycle flow rate R of 2.4 mgd and influent flow rates varying from 6 to 12 mgd per module, *i.e.*, for recycle ratios varying from 20 to 40 percent. The results of the computation are shown in Figure IV-4, and two points are readily apparent from the curves in this figure:

(1) The value of f assumed for the fraction of pressurized air input that is dissolved in the retention tank has a significant impact on $(A/S)_l$; at a Q of 12 mgd, $(A/S)_l$ equalled 0.026 at $f = 0.35$; whereas, $(A/S)_l$ equalled 0.058 at $f = 0.50$. Thus, the value of f must be closely defined (requiring presently unavailable metering) if an accurate measure of $(A/S)_l$ is to be obtained.

(2) The recycle ratio R/Q has a significant impact on the value of $(A/S)_l$; at a recycle ratio of 20 percent and $f = 0.50$, $(A/S)_l$ equalled 0.058, whereas, at a recycle ratio of 40 percent, $(A/S)_l$ equalled 0.116. Thus, a relatively constant $(A/S)_l$ value (required for process demonstration under steady-state conditions) cannot be obtained when Q is variant. It is also apparent that significantly higher $(A/S)_l$ values can be attained as the flow to each module is reduced below its nominal rated capacity of 12 mgd.



Because of the lack of definity of the f-parameter for the equipment at the Baker Street facility, it is recommended that an air flow meter be placed on the reject air lines from each retention tank as soon as possible.

HYDRAULIC CHARACTERISTICS

The hydraulic characteristics of the plant are of concern for two reasons:

(1) The impact of flow turbulence on air bubble-particle aggregates.

(2) The impact of varying liquid surface loading rates on the backwater height over the effluent launders, and the impact of the resultant backwater height on front and back skimming depth of the skimmer system.

As background information it is understood that for the demonstration program three of the four cells in each of the two flotation tanks may be closed down at the influent piping, pressurized (recycle) flow piping, and effluent launders, so that the probability of attaining at least a 3-mgd flow in one of the four cells during transient wet weather conditions is increased. This modified flow configuration (as compared with the design flow configuration) will also permit flow rates in excess of 3 mgd per cell, or liquid loading rates in excess of 6,000 gpd/sq ft, to be directed into the one open flotation cell. The maximum flow that can be passed through the one open flotation cell will be a function of the available head and the head losses in the entire system. While it is beyond the scope of the present report to conduct the hydraulic analyses required to estimate the maximum flow that can pass through a single flotation cell at the Baker Street facility, it is believed that because of the parallel flow configuration of the flotation cells, the maximum flow that can be passed through a single cell is less than the flow that can be passed through all four cells, i.e., less than 12 mgd.

Flow Relationships

The relationship between the influent flow rate to the module Q , the recycle ratio R/Q , and the flow rate into each flotator cell Q_1 at the Baker Street facility is important because of the impact of R/Q on $(A/S)_1$, discussed above, and because of the effect that the flow rate into the flotator ultimately has on the adhesion efficiency parameter (Chapter III). Two recycle modes can be used with the piping configuration shown in Figure IV-3:

(1) Flotator tank contents (withdrawn from a point just under the effluent launder) can be used as the input to the recycle loop, in which case the flow into the flotator is equal to $(R + Q)$.

(2) Raw influent (withdrawn from the main influent line through the diversion line shown in Figure IV-3) can be used as input to the recycle loop, in which case the flow into the flotation tank is equal to Q .

The relationships between the flow rate to each flotator cell Q , the recycle ratio R/Q , and the recycle mode are shown in Figure IV-5A for the design flow configuration and Figure IV-5B for the modified flow configuration.

As shown in Figure IV-5, the flow rates into each flotation cell for either mode of recycle, or either flow configuration, decrease with increasing recycle ratio when the recycle flow R is held constant at 2.4 mgd. The net effect of this relationship is two-fold:

(1) As the recycle ratio increases, the $(A/S)_1$ ratio increases (per Figure IV-4).

(2) As the recycle ratio increases, the flow rate into the flotation tank (Q_1) decreases.

Thus, from a theoretical standpoint, the effect of increasing the recycle ratio at a constant recycle flow rate is to increase the expected performance by *simultaneously* increasing the $(A/S)_1$ ratio and decreasing the Reynolds Number (associated with turbulence and aggregate shear) through the inlet manifold.

The relationships of Figures IV-5A and IV-5B can be used to identify the impact of the different flow configurations on Q_I . For the same recycle ratio the level of Q_I is four times greater with the modified flow configuration than with the design flow configuration. At the nominal influent flow rate Q of 3 mgd/cell, and with recycle loop intake from the flotator, Q_I is equal to 5.4 mgd and R/Q is equal to 60 percent for the modified flow configuration as compared to 3.6 mgd and 20 percent, respectively, for the design flow configuration. The ramification of these observations is that much higher Q_I values and inlet manifold Reynolds Numbers will obtain for the same level of influent flow rate Q when the modified flow configuration is used.

Reynolds Number Relationships in Inlet Manifold

Work by Ettelt and others (cited in Chapter III) has identified the inlet manifold design as being the critical factor affecting the adhesion efficiency parameter or the effective air:solids ratio $(A/S)_E$. A sketch of the inlet manifold configuration used in the Baker Street facility is shown in Figure IV-6. The key features of the design are:

(1) A pressurized flow inlet of 6-in. diameter and an 18-in. diameter main influent line converging at a common point on the manifold.

(2) Orifices (8-in. diameter) spaced at regular intervals on either side of the point of convergence of the above inlets. The "C" coefficient for the orifice in the equation $Q = CA(2gh)^{1/2}$ is 0.61.

There are three abrupt changes in direction of flow of the pressurized stream downstream from the pressure reducing valve: at a 90° elbow (not shown in Figure IV-6); at the point of convergence of the inlet pipes; and at the orifices.

Reynolds Number relationships have been calculated for the outlet orifices and are as follows:

$$N_R = \frac{Q_o D_o}{CA_n} = \frac{Q_I D_p}{CA_n} \quad (IV-1)$$



where: Q_0 = orifice flow rate, (cfs)
 Q_1 = flow rate into flotator cell, (cfs)
 N = number of orifices per cell, 14
 D = orifice diameter, 0.667 ft
 ρ = density of water, 1.94 lb-sec²/ft⁴
 C = orifice coefficient, 0.61
 A = orifice area, 0.349 ft²
 η = kinematic viscosity,
 2.10×10^{-5} lb/sec/ft² @ 68°F
 2.75×10^{-5} lb/sec/ft² @ 50°F

By substitution of the above into Equation IV-1, the Reynolds Numbers for the flow through the orifice (assuming uniform flow distribution through all 14 orifices in the inlet manifold to each cell) are:

(1) At 68°F:

$$N_R = 20,700 Q_1 \quad (IV-2)$$

(2) At 50°F:

$$N_R = 15,900 Q_1 \quad (IV-3)$$

For the recycle mode using flotation tank contents as input to the recycle loop, the flow rate to the inlet manifold flow rate for each cell is 5.58 cfs. At this flow rate, the Reynolds Number through the orifice is 87,000 at 50°F and 108,000 at 68°F. The impact that these Reynolds Number levels have on process performance at the Baker Street facility remains to be documented in the demonstration program.

Effluent Launderers

A curve relating the height of the backwater behind the effluent launders with the effluent flow rate to each cell is presented in Figure IV-7. The maximum weir height available is 5.5 in. and there are a total of 158 weirs per flotation tank, or 39.5 weirs per flotation cell. The backwater height required at a nominal design



flow of 3 mgd/cell is 0.29 ft or 3.5 in., and the maximum flow that can pass over the weirs without surcharging the launders is 9 mgd/cell. It is unknown at present what effect the change in backwater level with increasing flow will have on the performance of the skimmer systems. Because the front skimming depth is adjustable from 0 to 2 in., and the back-skimming depth from 0 to 1 in., it is anticipated that the appropriate skimming depths for optimal rate to the cell will vary. Some consideration will be given to this factor in the demonstration program.

SUMMARY OBSERVATIONS ON AVAILABLE OPERATING MODES

With the design flow configuration available in the Baker Street facility (four flotation cells operative per module; 12-mgd rated capacity per module), the following operating modes are possible:

(1) Variation of specific chemical doses for any mode of recycle, influent flow rate, or $(A/S)_1$.

(2) Variation of skimmer system settings for any mode of recycle, influent flow rate, or $(A/S)_1$.

(3) Variation of $(A/S)_1$ at a constant recycle ratio, solids loading rate, and liquid loading rate (flow ratio into each flotation cell, Q_1) by throttling the net air input to the recycle system. The curves shown in Figure IV-4 define the maximum $(A/S)_1$ that can be achieved for selected module Q and for the assumptions used in preparing the figure.

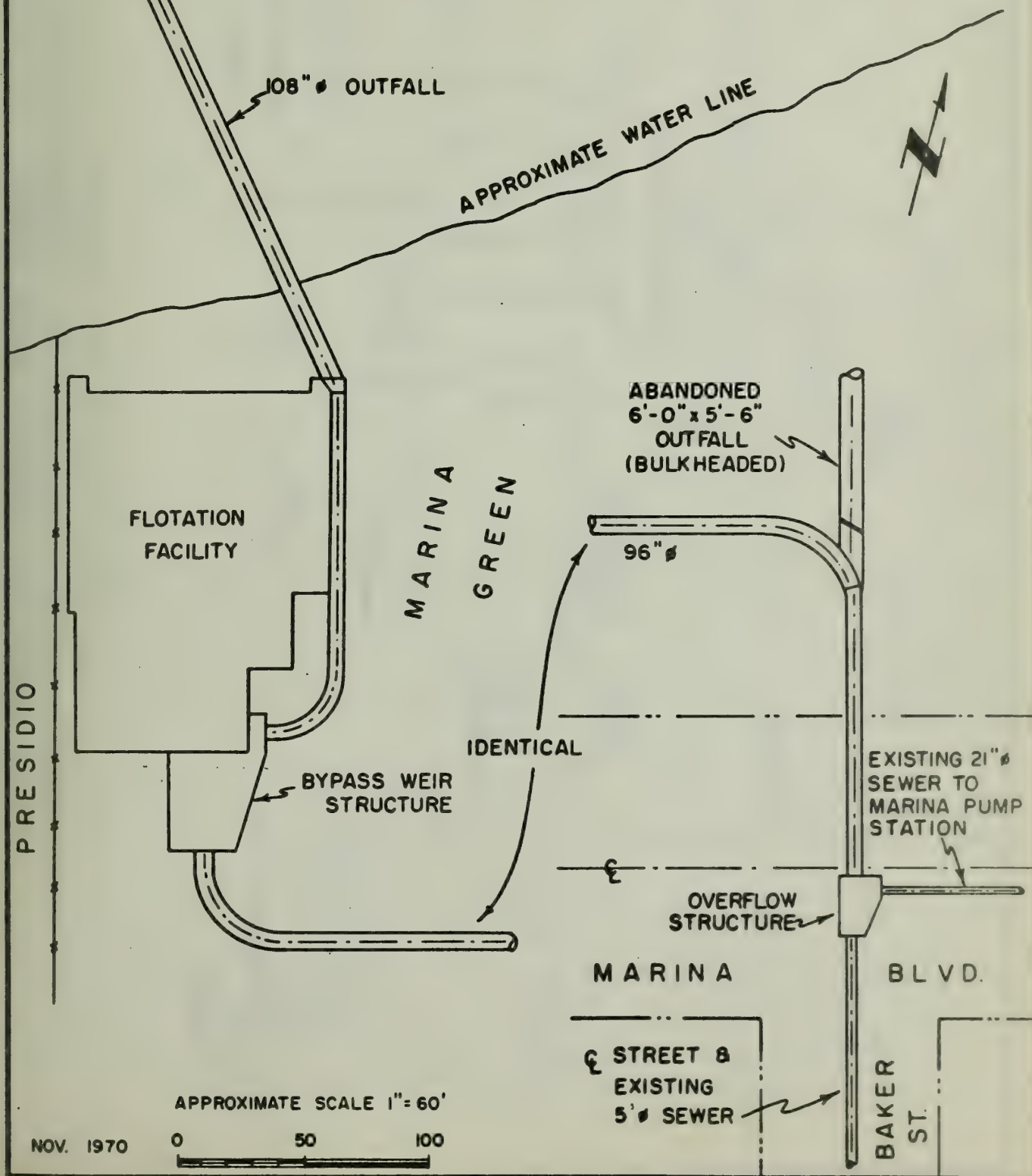
(4) Variation of the flow rate into the flotator cell (Q_1) at constant recycle ratio $(A/S)_1$ and solids loading rates by varying the mode of recycle (first, recycling from the flotator, and second, from the influent). Two liquid loading rates into the flotation cells can be considered per selected recycle ratio as defined by the relationships shown in Figure IV-5A.

With the proposed modified flow configuration (where all the flow into a module is diverted into one cell), the above four



relationships hold with the exception that the relationship between Q_1 and R/Q for the modified flow configuration is as shown in Figure IV-5B

LOCATION MAP BAKER STREET OUTFALL DISSOLVED AIR FLOTATION FACILITY MARINA GREEN-SAN FRANCISCO

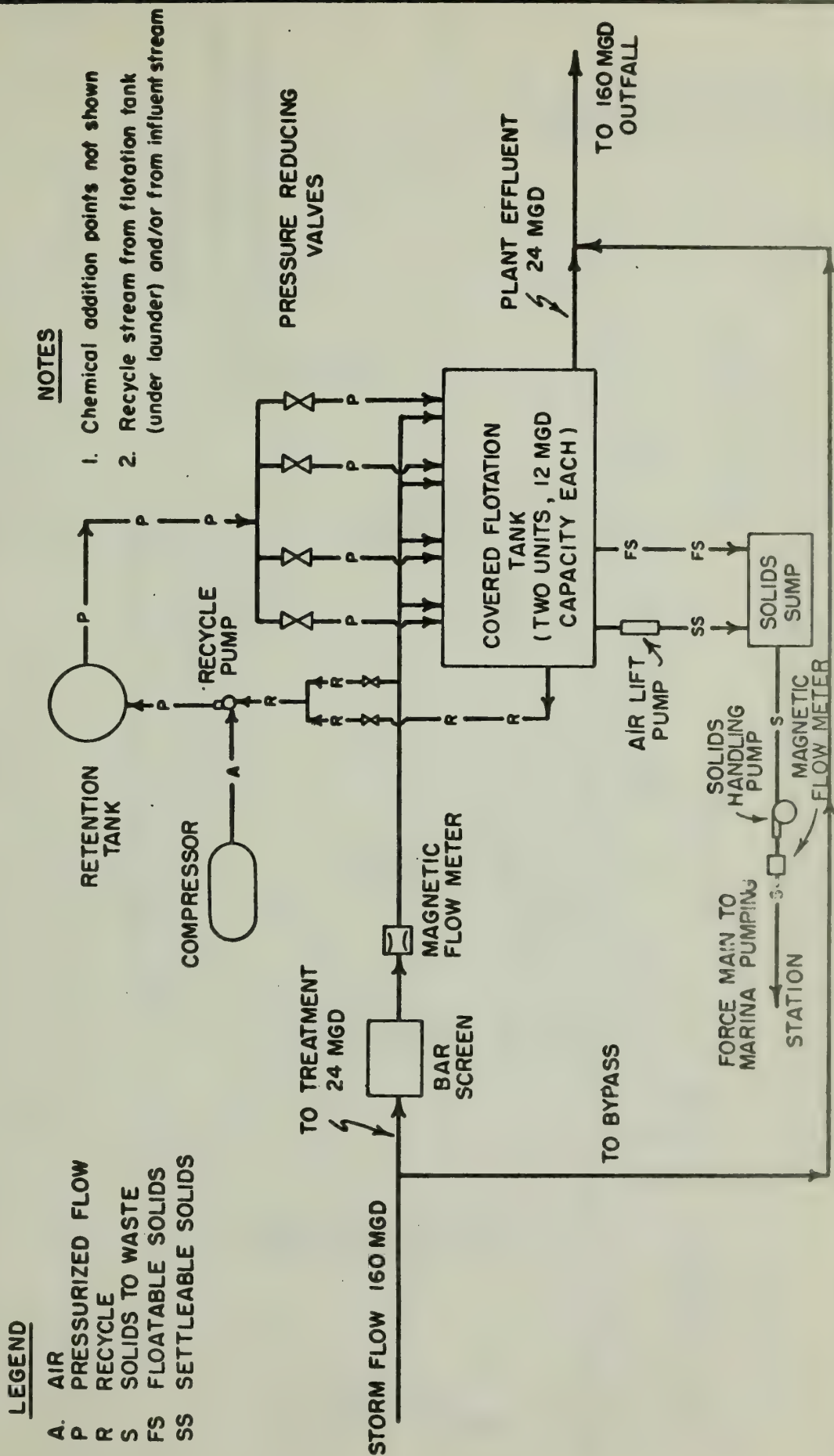




SIMPLIFIED PROCESS FLOW SHEET

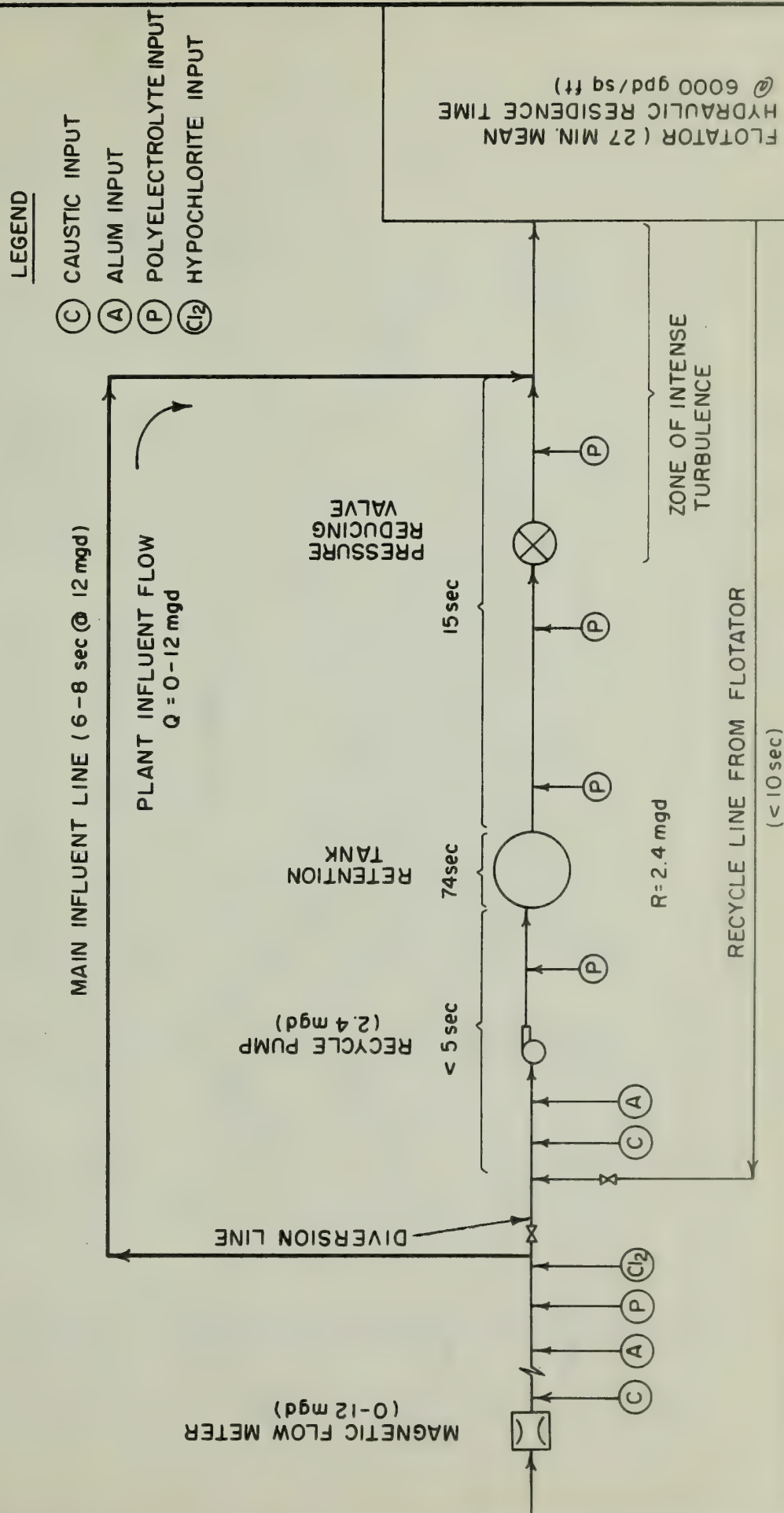
BAKER STREET OUTFALL DISSOLVED AIR FLOTATION FACILITY

CITY AND COUNTY OF SAN FRANCISCO



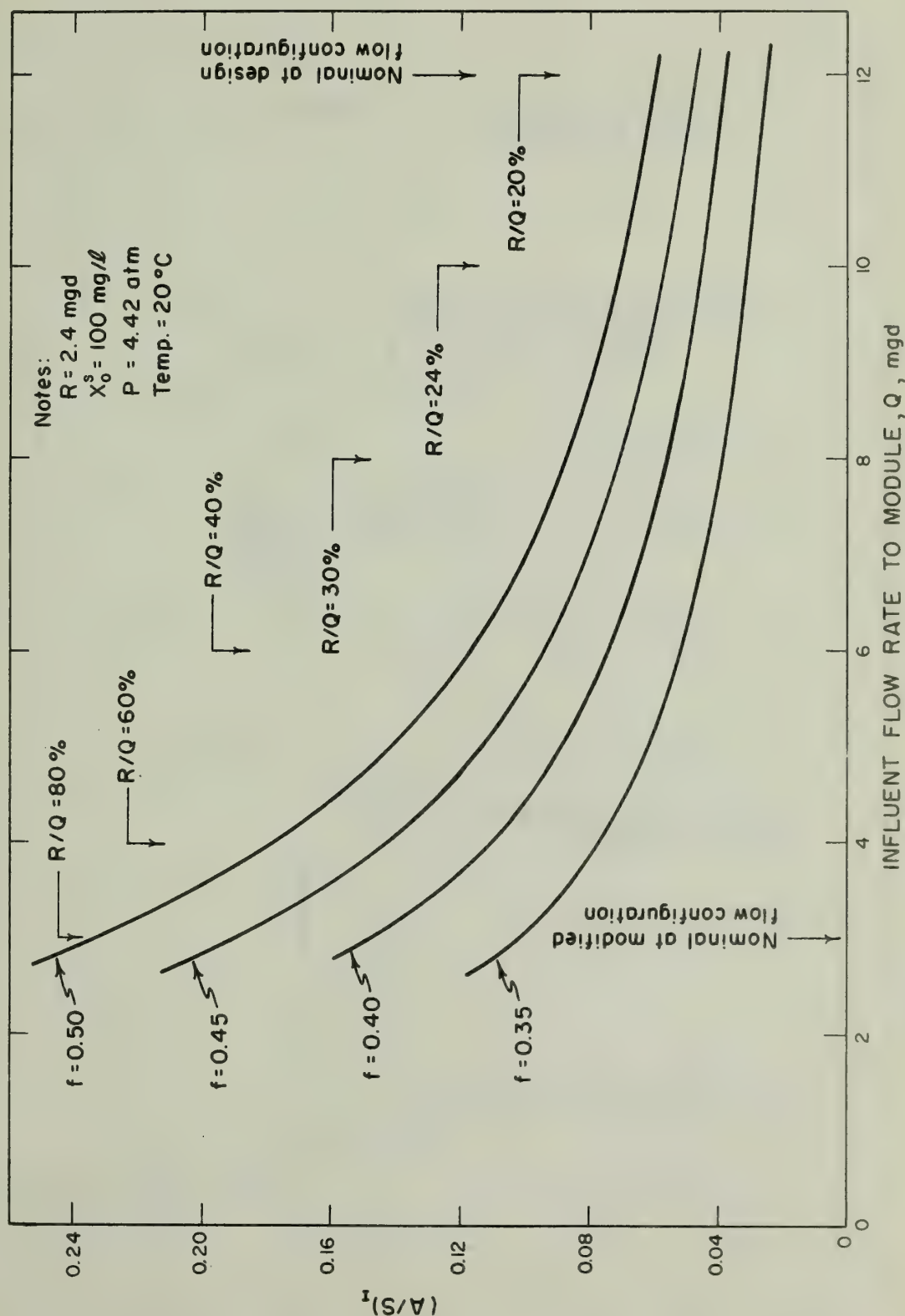


BAKER STREET DISSOLVED AIR FLOTATION FACILITY CHEMICAL ADDITION AND RECYCLE OPTIONS FOR EACH FLOTATION TANK (SKETCH SHOWING RECYCLE FROM FLOTATOR)



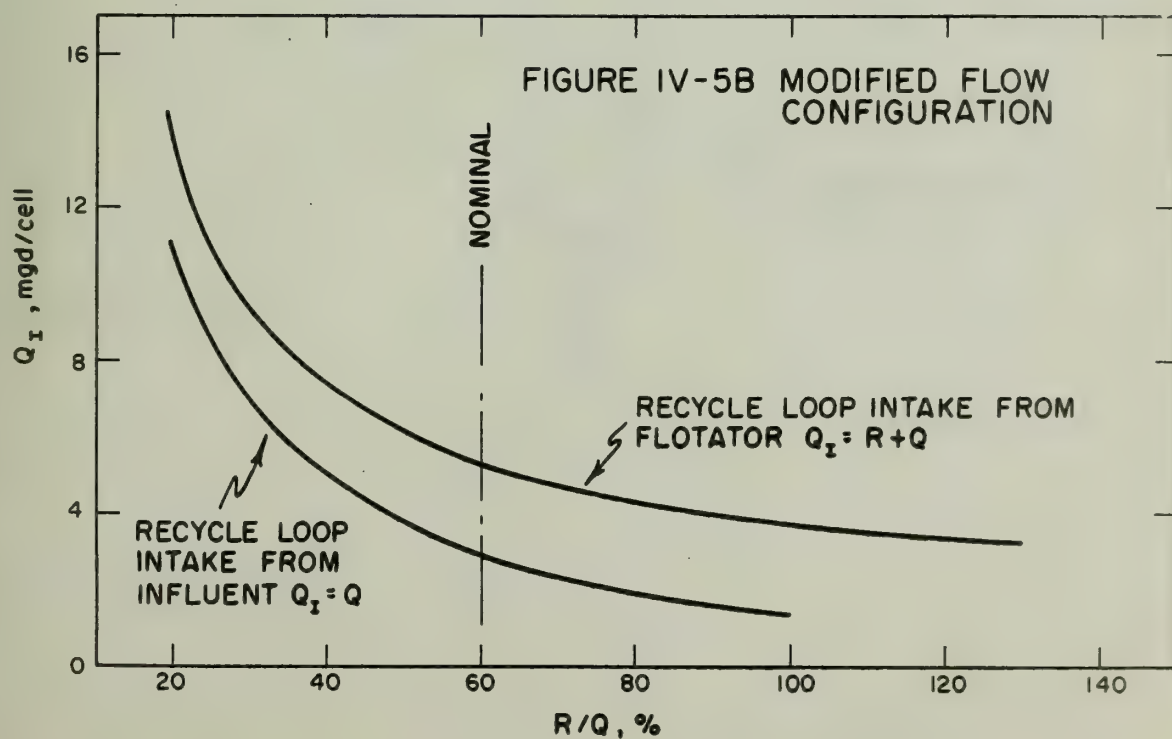
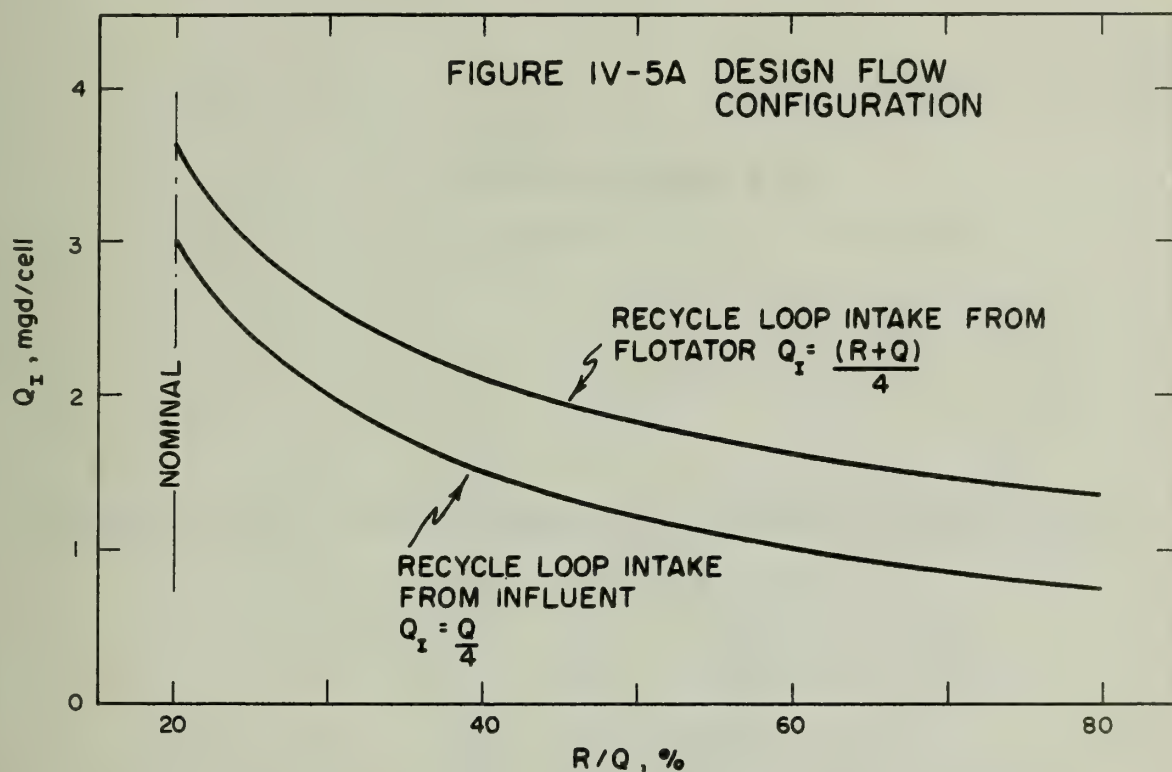


RELATIONSHIP BETWEEN $(A/S)_I$, INFLUENT FLOW RATE TO MODULE, Q, AND FRACTION OF PRESSURIZED AIR INPUT DISSOLVED





EFFECT OF RECYCLE RATIO R/Q ON FLOW RATE
INTO FLOTATOR CELL Q_I AT RECYCLE FLOW OF 2.4 mgd CONSTANT



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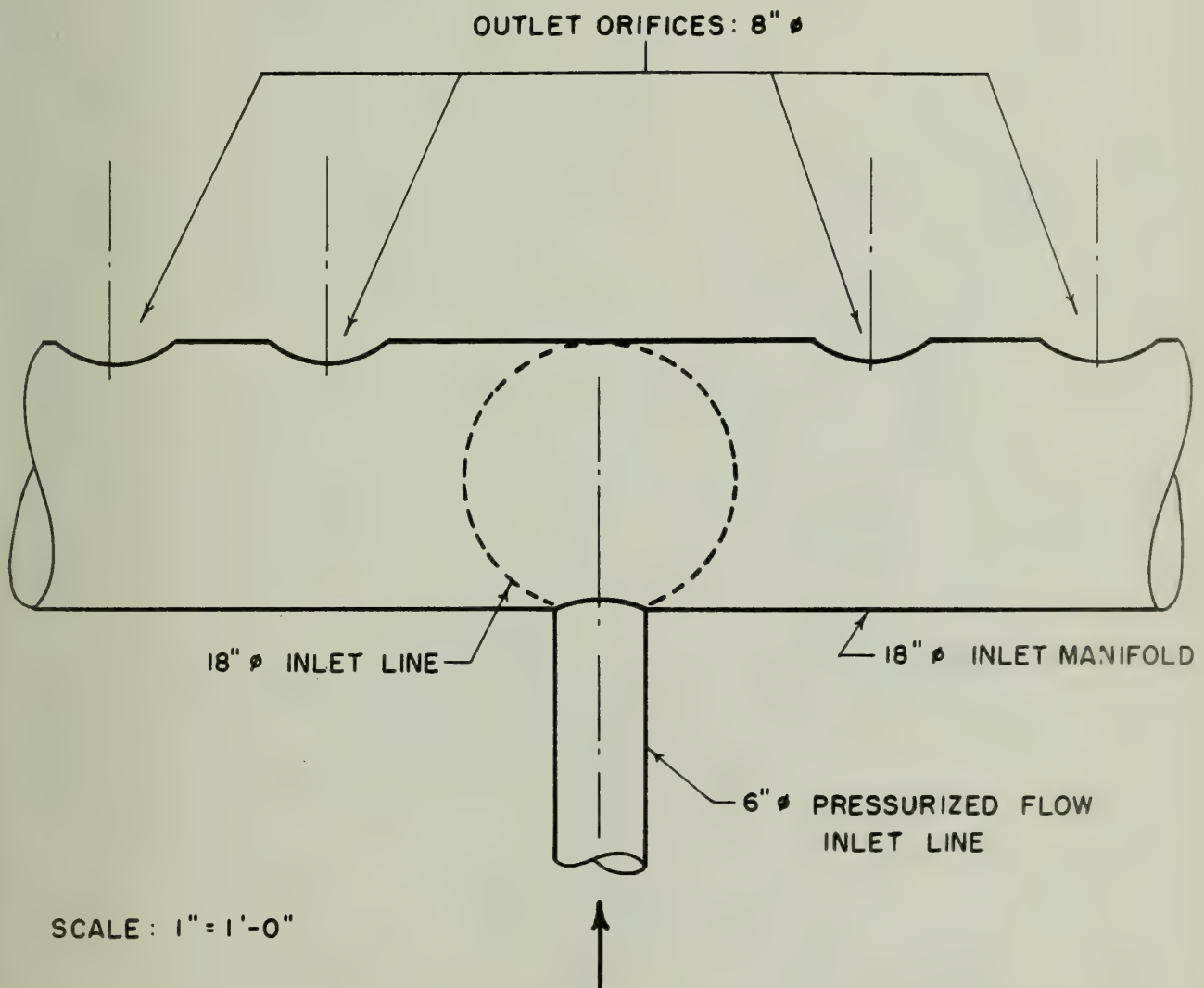
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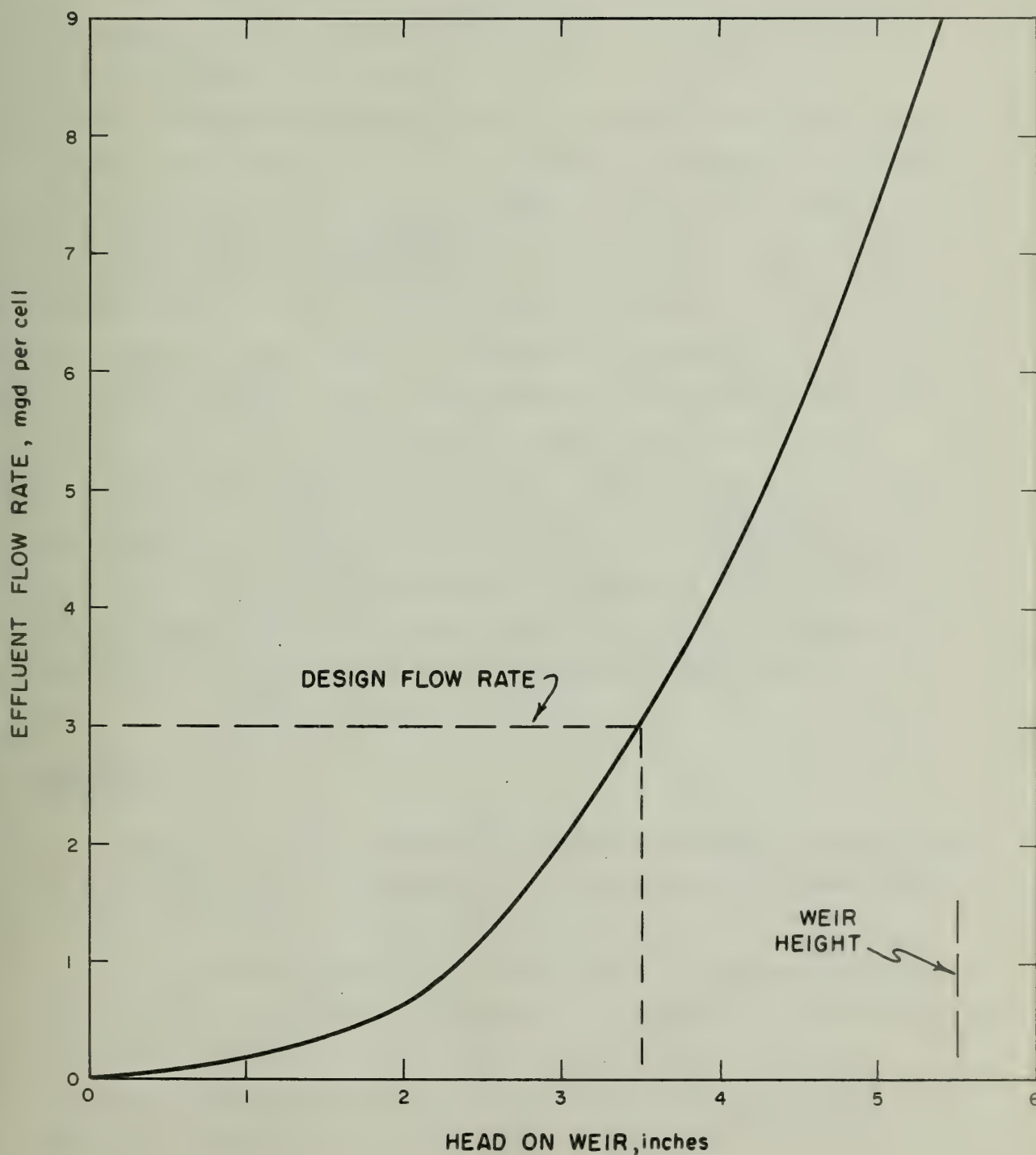
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INLET MANIFOLD CONFIGURATION





RELATIONSHIP BETWEEN EFFLUENT FLOW RATE AND HEAD ON WEIR BAKER STREET DISSOLVED AIR FLOTATION FACILITY





CHAPTER V

LABORATORY STUDIES ON CHEMICAL REQUIREMENTS FOR DISSOLVED AIR FLOTATION OF COMBINED SEWER OVERFLOWS

At the time of the initial planning and subsequent design of the dissolved air flotation facility at Baker Street it was anticipated that a chemical scavenger, or scavengers, would be required for the facility to achieve the desired performance level. In order to gain some insight as to the possible types and quantities of chemical scavengers which might be most effective in promoting solids separation of combined sewer overflows in the operations of the dissolved air flotation unit, a very limited laboratory study was conducted prior to the facility design. Based on the results of this very cursory study, equipment and systems for adding alum, caustic, and polymer were included in the design and construction of the Baker Street facility. This equipment includes proportional pumps, storage tanks, and multiple points of chemical addition. However, prior to the full-scale operation of the Baker Street facility for the purpose of obtaining unit operation performance data, it was deemed mandatory to obtain detailed information as to the chemical requirements appropriate to the specific dissolved air flotation unit operation application. Without such information the entire field program could have been devoted to establishing the appropriate chemical dosages without obtaining any meaningful operational characterization data.

OBJECTIVES

In order to develop information on specific chemical dosage criteria for the operation of the dissolved air flotation facility, the laboratory program was designed.

(1) To develop estimates of chemical dose requirements for floc formation using alum, caustic, and polymer in combination and polymer alone in jar test sequences.

(2) To define and confirm the above chemical doses by assessing the removal of suspended solids and floatable materials over a range



of chemical doses in a laboratory batch flotation cell.

(3) To formulate specific chemical dose criteria through use of the results of the above tests for subsequent ultimate confirmation in prototype operation.

BACKGROUND INFORMATION

Wastewater Characterization

The basic factors which will determine the actual dosages of chemicals to be used in the Baker Street dissolved air flotation facility are (1) the chemical demand of the wastewater to achieve a desired or maximal suspended solids and/or turbidity removal, and (2) the time-variant characteristics of the wastewater parameter which controls the relative chemical demand of the wastewater for the purpose of dissolved air flotation. That is, one factor defines the mass/mass requirements for chemicals and the other defines the mass/time factor, or rate at which chemicals will have to be added. The former is a consequence of the laboratory effort, whereas, the latter is determined by the time variation of the quantity and quality of combined sewage inflow over the period of discharge to the dissolved air flotation unit. There are two basic approaches which can be used to define the rate of chemical addition one involves a prediction of the change in quantity of wastewater and the control parameter over time resulting in a pre-programmed change in chemical addition over the time of the operation of the dissolved air flotation unit; the other approach involves real-time measure of flow rate and the critical parameter concentration to permit continuous adjustment of the chemical addition rate.

Consistent with the first of the above approaches, an attempt was made to ascertain if a relationship exists between the time from the start of the overflow of the combined sewage and the suspended solids concentration in the wet-weather sewage flow, where suspended solids were perceived to be the control parameter. The basic data for this relationship were obtained from Reference 9, and are shown in Figure V-1, which is a plot of all suspended solids data obtained from both the



dry- and wet-weather monitoring at Baker Street. The diurnal variation in dry-weather suspended solids concentration exhibits a pattern in which:

(1) Peak levels between 150 and 200 mg/l occurred from 0500 to 0900 hours.

(2) Levels between 100 and 150 mg/l occurred from 1200 to 0700 hours.

(3) Levels less than 100 mg/l occurred from 1200 to 0700 hours. This pattern is typical for wastewaters of domestic origin.

The time-variant patterns of the suspended solids levels for the three combined sewage flows exhibited two characteristics:

(1) Initial peak levels occurred from one to two hours after the start of overflow and were equal to from two to three times the time-correspondent dry-weather suspended solids concentration.

(2) After attenuation of initial peak levels, the suspended solids levels paralleled within ± 50 percent those of the time-correspondent levels in the dry-weather flows.

In view of the wide spread in the suspended solids levels shown in Figure V-1 (not unexpected in view of the numerous system dependent factors controlling the instantaneous suspended solids levels of the wastewater) it became apparent that a form of criterion other than one based on an *a priori* knowledge of the suspended solids parameter must be considered for controlling the rate of chemical addition.

The alternative to the above (the real-time approach) was to attempt to develop a correlation between turbidity and suspended solids levels, and to use this correlation, coupled with mass/mass criteria developed in the present study on the basis of suspended solids levels, as a means of adjusting *in situ* the chemical doses applied on the basis of influent stream turbidity measurements made at regular intervals during a monitoring operation. The correlation curves and dosage criteria developed using the above approach

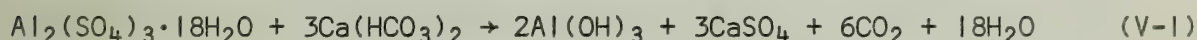
are presented subsequently in this chapter.

Selection of Chemicals

The types of chemicals which will be available in the dissolved air flotation facility have been described in Chapter IV and are alum, caustic, and polyelectrolytes. The polyelectrolytes to be considered in the laboratory study were based on prior experience with both cationic Dow Purifloc C-31, used in laboratory flotation tests utilizing combined sewage (Reference 10) and anionic Dow Purifloc A-23, used to treat domestic sewage at the Pacific Grove Sewage Treatment Plant (Reference 11). Because of successful prior experience with these polymers, both were evaluated by jar testing.

Stoichiometry of Alum Reactions

The stoichiometric relationships for the reaction of alum and alkalinity to produce aluminum hydroxide (a hydrated metal oxide form) are:



and:



Based on the above stoichiometric relationships 666 mg of alum, or 432 mg $\text{Al}_2(\text{SO}_4)_3$, reacts with 486 mg of $\text{Ca}(\text{HCO}_3)_2$ to produce two moles of aluminum hydroxide and six moles of carbon dioxide. The carbon dioxide requires six moles of hydroxide in order to neutralize the resulting carbonic acid. Thus, 40 mg NaOH is required to neutralize the acidity produced by the reaction of 111 mg of alum or 57 mg $\text{Al}_2(\text{SO}_4)_3$ with natural bicarbonate alkalinity.

Aluminum hydroxide is an amphoteric material whose minimum solubility occurs in the pH range of 5 to 7. The K_{sp} of aluminum hydroxide in the acid solubilization reactions is 1.9×10^{-23} at 25°C. The effectiveness of aluminum hydroxide is determined primarily by its zeta potential which, depending on the ionic species in the medium and the zeta potential of other colloidal material, is minimal in the pH range associated with minimum solubility.

Wastewater Samples

Wastewater samples for both the jar tests and subsequent flotation cell tests were obtained from the Baker Street sewer at a man-hole at Baker and Jefferson Streets. A total of four samples were obtained and transferred to the laboratory for analysis for total suspended solids, turbidity, pH, and alkalinity. Dilution curves were run for each of the four samples and the turbidities of the diluted samples were measured using a Hach Model 1860 turbidimeter. The resultant data were plotted against the suspended solids concentration as shown in Figure V-2, and a single correlation line relating turbidity and suspended solids concentration was obtained for all samples:

$$\text{JTU} = 0.36 X_{\text{O}}^{\text{S}} - 4 \quad (\text{V-3})$$

where: JTU = Jackson Turbidity Units

X_{O}^{S} = total suspended solids concentration (mg/l)

The correlation relationship of Equation V-3 was used in both the jar tests and flotation cell tests to convert turbidity readings in samples taken after chemical addition to suspended solids levels, and (as discussed later) in defining manual control settings on the chemical feed pumps relative to influent turbidity. The implicit assumption in the former use of the correlation is that the apparent (dissolved) turbidity decreased proportionally to suspended solids levels as a function of the treatment effected.

JAR TESTS

Methodology

The procedure for a jar test consists of a rapid mixing of the chemical and samples for about one minute to obtain a uniform distribution of coagulant. The rapid mixing is followed by a flocculation step which involves stirring at a slower rate than that required for rapid mixing (range 10 to 40 rpm) to promote contact between the



destabilized dispersed particles. The final step is to permit quiescent settling.

The apparatus used consisted of a standard jar test unit as described in *Standard Methods*. A departure from the methodology of *Standard Methods* for the jar tests was used in the program because of the physical characteristics of the Baker Street facility. Specifically, a rapid mix of two minutes duration was used throughout the experiments to simulate mixing time (under two minutes) in the recycle loop of the prototype. The settling time of 20 minutes was used in the jar tests to simulate the detention time in the flotation tank. Chemical dosages and chemical feed dilutions were based on prototype specifications as described in Chapter IV. After mixing, the contents of the jars were observed for floc formation and settleability. Samples were taken from each jar from the same depths and analyzed for pH and turbidity. Turbidity readings were converted to suspended solids concentrations by means of the correlation curve of Figure V-2. Eight jar tests were conducted; the first two tests were performed to establish the dosage of alkalinity (as caustic) required at various alum dosages up to 240 mg/l.

Preparation of Chemicals

The stock solutions prepared for the laboratory tests and used throughout the jar testing are described in Table V-1.

TABLE V-1
STOCK SOLUTIONS

Chemical	Concentration (mg/l)
Alum, @ $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$	10,000
@ $\text{Al}_2(\text{SO}_4)_3$	5,120
Caustic Soda, NaOH	1,000
Dow Purifloc A-23	100
Dow Purifloc C-31	1,100

Results

The experimental data are presented in Table C-1 through C-8 of Appendix C and summarized in Figures V-3, V-4, and V-5. In the test using alum alone (Figure V-3), there was a marked change in suspended solids removal (from 40 percent to 70 percent) when alum dosage increased from about 1.6 mg/mg TSS to 1.8 mg/mg TSS. The optimum dosage with alum as the only chemical addition to the test sample (which had an initial alkalinity of 200 mg/l as CaCO_3) was found to be 310 mg/l or 2.2 mg/mg TSS, corresponding to a solids removal of 89 percent.

Initial testing showed that the polymer C-31 was more effective than A-23 in solids removal (Tables C-5 and C-6 of Appendix C). From the results of complete testing with C-31, shown in Figure V-4, it was found that the optimum polymer C-31 dosage was within the range of 0.01 to 0.03 mg/mg TSS.

The results of the jar tests using the two chemicals in combination are shown in Figure V-5. When alum was dosed at 1.08 mg/mg TSS and the polyelectrolyte dosage varied from 0.005 to 0.015 mg/mg TSS (Table C-7 of Appendix C), poor suspended solids removals were obtained. The effluent at this dosage rate was in each case more turbid than was the initial test sample. The results of higher alum dosages (1.8 and 2.15 mg/mg TSS) are presented in Figure V-5, in which case an optimum C-31 dosage range of 0.015 to 0.02 mg/mg TSS was indicated for both specific alum doses.

LABORATORY FLOTATION CELL STUDIES

The jar tests described previously represent a form of assay which is based on floc formation and settleability, and the results of these tests have provided general criteria for chemical doses. However, the effectiveness of chemical treatment, based on these dosage criteria, can be evaluated only insofar as they improve the performance of the flotation process. For this reason, it was deemed expedient to use laboratory flotation cell performance as a



second-level assay for refining the chemical dose criteria before actual prototype testing was begun.

Objectives

The objectives of the laboratory flotation cell study were to evaluate the suitability of the optimum chemical coagulant dosages from the jar tests in a laboratory-scale flotation cell on the basis of effluent quality and floated solids production.

Methodology

The laboratory flotation cell apparatus (Figure V-6) consisted of a lucite flotation chamber (9-ft high by 4-in. ID) and a steel pipe pressurizing tank (8-ft long by 4-in. ID). The lucite cell had eight vertical sampling ports at 12-in. intervals.

The tests involved filling the flotation and pressure cells with a total sample volume of 20 liters. All chemicals were added, in quantities to yield the desired final doses, to the 4-liter portion of the 20-liter sample that was loaded into the pressurizing tank. Compressed air was then bubbled through the aliquot in the pressurizing tank for 10 minutes at a pressure of 65 psig in order to accomplish the solution of air and the mixing chemicals. The pressure for all tests was kept constant at 65 psig, using an air release valve and pressure indicator at the top of the pressure tank. The pressurized portion was then released into the flotation cell and the exact time of transfer was recorded.

A stop watch was started just as the transfer was completed and samples were taken at various times from the sampling ports over a 30-min interval for analysis of turbidity and floatables. The turbidity values were converted to suspended solids values by means of the turbidity-suspended solids correlation curve of Figure V-2. The initial test sample and final effluent were analyzed for total suspended solids, alkalinity, and floatables. The float (scum) was skimmed off the liquid surface and analyzed for total suspended solids.

A total of 16 runs was made with the following chemical dose patterns being used:

(1) Run 1: No chemicals.

(2) Runs 2 to 11: Both alum and polymer, in the following dosage sequences:

(a) Alum @ 1.6 mg/mg TSS; polymer (C-31) @ 0.018 mg/mg TSS.

(b) Alum @ 1.8 mg/mg TSS; polymer @ 0.015, 0.018, 0.02, 0.029, and 0.036 mg/mg TSS.

(c) Alum @ 2.15 mg/mg TSS; polymer @ 0.015 and 0.036 mg/mg TSS.

(3) Runs 12 to 16: polymer alone at 0.01 to 1.02 mg/mg TSS.

Results

The basic laboratory data from the flotation cell experiments are summarized in Tables C-9 to C-27 of Appendix C. A summary of the results is presented in Table V-2 and discussed below.

As reference information for data evaluation, a suspended solids removal of 36 percent after 30 minutes was achieved in Run 1 using no chemicals.

Suspended Solids and Floatable Material Removal Efficiencies

The basic data in Appendix C have been analyzed using the procedure for Class II clarification (Appendix A) and the resultant relationships between (total) suspended solids removal efficiency and effective surface loading rate (gpd/sq ft) for Runs 4 to 11 are shown in Figure V-7. A consistently decreasing trend in suspended solids removal efficiency with increasing effective surface loading rate was observed for all runs. The highest removal efficiencies were between 60 and 70 percent for alum/polymer doses of 2.15/0.015 mg/mg TSS and 1.8/0.018 mg/mg TSS. Performance for the other alum/polymer dose levels varied from 25 to 60 percent suspended solids removal efficiency, even though the doses were, in most cases, similar in magnitude to those reported above for the optimal removal



TABLE V-2
SUMMARY OF RESULTS OF
LABORATORY FLOTATION CELL TESTS

Run	Specific Chemical Doses (mg/mg TSS)		Average Inlet N _R	% Removals at 30 Minutes		Float Character		Input Suspended Solids Recovery @ Float (%)
	Alum	C-31		TSS	Floatable Materials	TSS (mg/l)	Mass (mg)	
1	-	-	3,700	37.0	-	-	-	-
2	1.80	0.018	3,240	62.6	66.6	1,610	-	-
3	1.60	0.018	3,900	27.9	53.4	2,280	700	22.8
4	1.80	0.020	3,350	22.8	86.6	2,360	740	23.3
5	2.15	0.029	2,420	63.6	95.5	2,680	840	31.5
6	2.15	0.036	4,740	72.6	97.6	3,670	1,230	46.5
7	2.15	0.015	4,220	56.0	97.6	2,430	970	36.7
8	1.80	0.018	3,880	66.6	96.0	4,090	1,620	61.3
9	1.80	0.015	5,460	43.8	95.7	1,220	380	11.9
10	1.80	0.029	2,630	67.4	87.0	4,520	1,600	50.0
11	1.80	0.036	2,830	63.8	95.7	2,490	1,040	32.4
12	-	0.010	4,220	70.0	99.0	755	60	1.4
13	-	0.025	3,400	55.0	94.0	313	33	1.1
14	-	0.060	3,800	66.0	96.0	-	-	-
15	-	1.020	5,200	63.0	96.0	-	-	-
16	-	0.035	3,400	77.0	96.0	-	-	-

NOTES: (1) Total sample volume @ 20 l, 4 l of which was pressurized at 65 psig.

(2) Reynolds Number values from Table C-11.



efficiencies.

In order to permit evaluation of the tradeoffs between alum and polymer doses, Figure V-8 was prepared using the suspended solids removal efficiencies obtained for each dose pattern at an effective surface loading rate of 6,000 gpd/sq ft, the nominal liquid loading rate for the Baker Street facility. It is apparent from Figure V-8 that increased specific polymer doses did not improve the removal efficiency for the specific alum dose of 2.15 mg/mg TSS but did effect improved removals at the specific alum dose of 1.8 mg/mg TSS. On the basis of these results, the optimum dosage pattern using both alum and polymer was 2.15 mg alum/mg TSS and 0.015 mg (C-31)/mg TSS. The data base did not permit extrapolation to specific polymer doses less than 0.015 mg/mg TSS; however, this factor, as well as the effect of increasing specific polymer doses at lower specified alum doses, will be confirmed in the demonstration program.

The removal efficiencies for floatable materials with alum and polymer conditioning (also shown in Figure V-8) varied between 85 and 95 percent for all the dosage patterns considered, with the best removals being obtained at a specific alum dose of 2.15 mg/mg TSS.

The relationships between suspended solids removal efficiency and effective surface loading rate for Runs 12 to 16 (polymer only) are shown in Figure V-9, and the relationships between specific polymer dose and solids removal efficiency at a constant effective surface loading rate of 6,000 gpd/sq ft are shown in Figure V-10. The range of removal efficiencies with polymer alone varied from nearly 60 percent, at a specific polymer dose of 0.035 mg/mg TSS, to 20 percent, at a specific polymer dose of 0.025 mg/mg TSS. As shown in Figure V-10, the optimum polymer dose in terms of suspended solids removal, at an effective surface loading rate of 6,000 gpd/sq ft, was 0.035 mg/mg TSS. No optimum polymer dose was indicated for removal of floatable materials, inasmuch as removal efficiencies in excess of 90 percent were obtained for all specific polymer doses tested.



Float Characteristics

The characteristics of the float obtained in the experimental runs are reported in Table V-2. Several trends were noted in the results:

(1) The highest recoveries of input suspended solids as float (40 to 60 percent) were observed in the runs using specific alum doses of 1.8 and 2.15 mg/mg TSS; however, it is unknown what fraction of the suspended solids recovered as float is precipitated alum.

(2) The recoveries of input suspended solids in the float varied between one and two percent when polymer alone was used. Inasmuch as similar levels of floatable removal efficiencies were observed for both polymer alone and polymer in combination with alum, it is believed that the floats developed in the runs using polymer alone contained significantly greater levels of floatable materials.

Inlet Reynolds Number parameters were calculated for each run on the basis of the transfer velocity equivalent to the average time required for transfer of the pressurized portion of the test sample into the flotation cell, and the density and viscosity of water at the temperature of the sample. A correlation was attempted between this parameter and the mass of float formed in each run (using the data of Table V-2) to ascertain if the inlet hydrodynamics of the laboratory flotation cell had an effect on float formation. These parameters are plotted in Figure V-11 for a range of N_R between 2,400 and 5,500 (or 2 to 5 percent of N_R levels expected in the inlet of the prototype), and no general trend was indicated. It was concluded that within the range of inlet Reynolds Numbers observed in the laboratory program, this parameter was not a significant factor affecting the performance levels observed in the batch tests.

SUMMARY AND RECOMMENDATIONS

Summary

The chemical coagulants tested in this study successfully effected floc formation, suspended solids removals, and float production. A combination of alum and cationic polymer conditioning (with adequate alkalinity added when necessary) produced better removals of suspended solids, but similar removals of floatable materials, than did treatment with cationic polymer alone. Although the alkalinity of the wastewater samples was sufficient for the alum levels tested, it would appear efficacious as a precautionary measure that alkalinity (as caustic soda) be added in the demonstration program in an amount equal to either one-fourth the stoichiometric requirements for the alum dosage, or as required to maintain a pH of 7.0, whichever is less.

The approximate optimum dosage range indicated from the jar tests were:

- (1) Alum and polymer:
 - (a) Alum: 1.8 mg/mg TSS.
 - (b) Polymer: 0.015 to 0.02 mg/mg TSS.
- (2) Polymer alone: 0.03 mg TSS.

The optimum dosage levels indicated as a result of the flotation cell tests were:

- (1) Alum and polymer:
 - (a) Alum: 2.15 mg/mg TSS.
 - (b) Polymer: 0.015 mg/mg TSS.
- (2) Polymer alone: 0.035 mg/mg TSS.

A correlation was developed between turbidity and suspended solids concentration for wastewater samples taken from the Baker Street sewer (Figure V-2) which is as follows:

$$JTU = 0.36 X_{O}^S - 4 \quad (V-3)$$

where: JTU = Jackson Turbidity Units.

X_O^S = total suspended solids concentration (mg/l)

Recommendations

On the basis of the above findings, the following recommendations are made for the demonstration program:

(1) Prototype evaluation should be made to define the optimum chemical doses on the basis of prototype performance; the range of doses to be investigated being as follows:

(a) Alum and polymer in combination.

(1) Alum: 1.8 to 2.2 mg/mg TSS or 0.93 to 1.13 mg $Al_2(SO_4)_3$ /mg TSS.

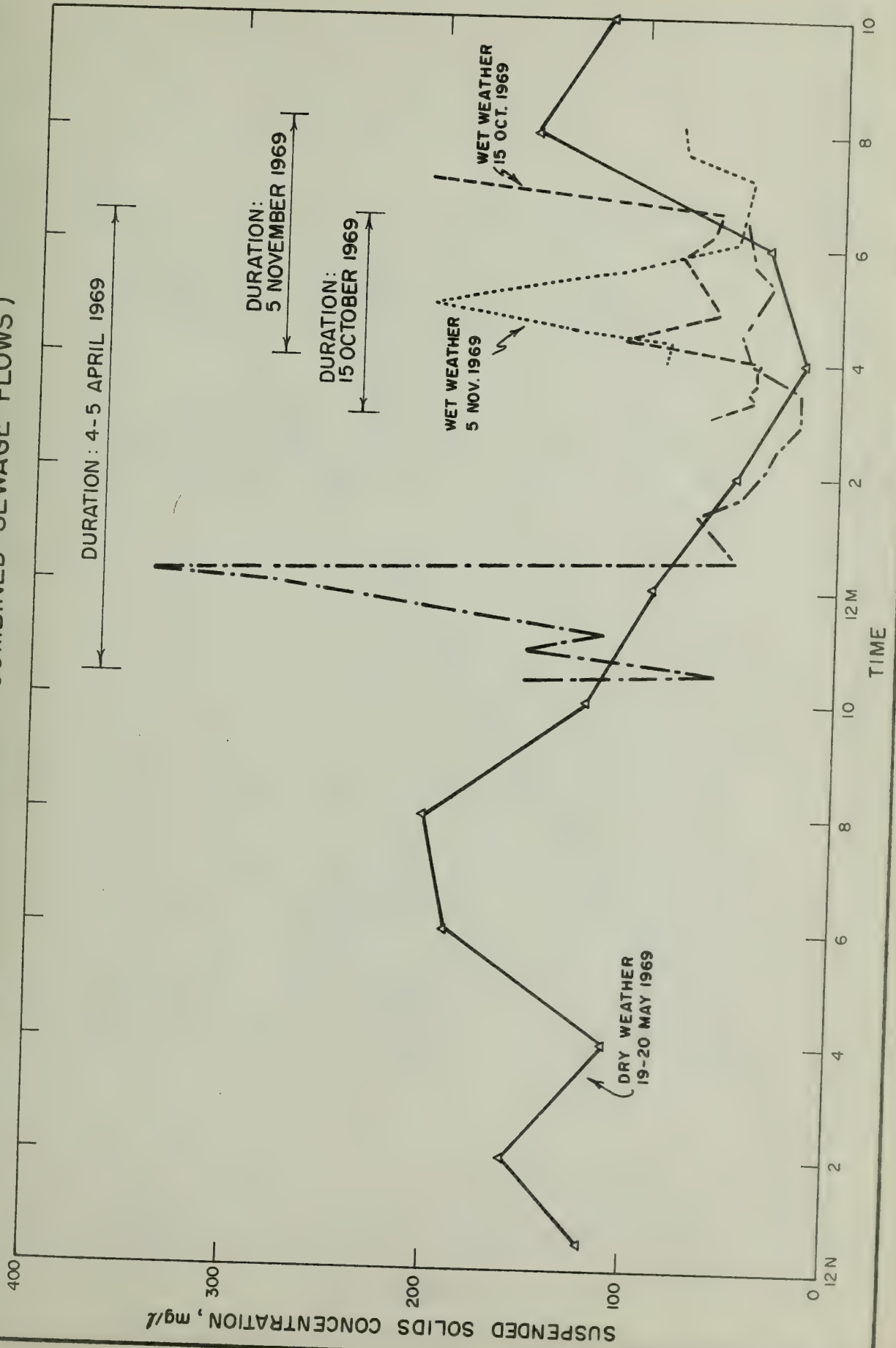
(2) Polymer: 0.015 to 0.02 mg/mg TSS.

(b) Polymer: 0.03 to 0.05 mg/mg TSS.

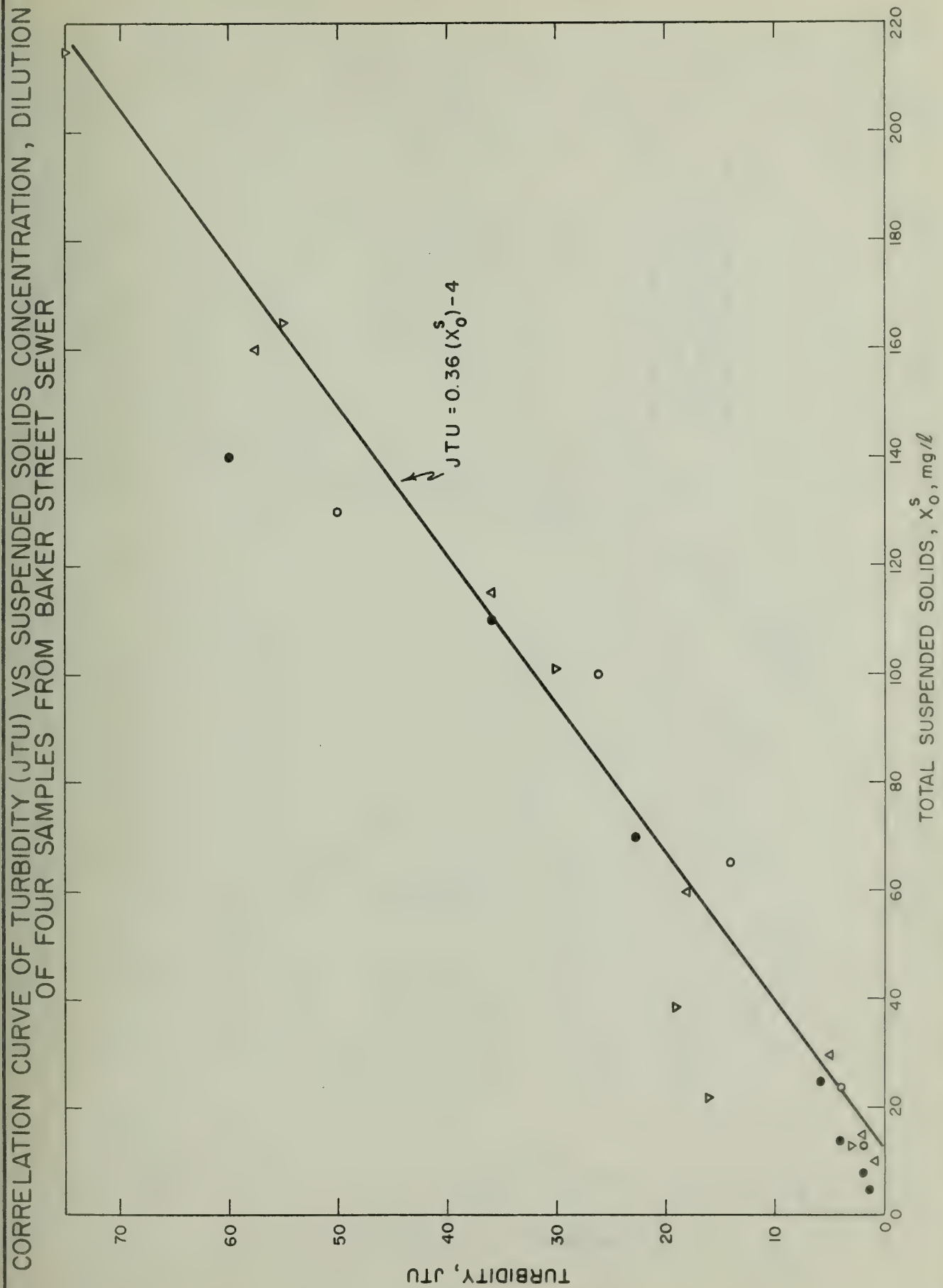
(2) Alkalinity as caustic soda should be added in an amount equal to either one-fourth the stoichiometric requirements of the alum dosage, or as required to maintain a pH of 7.0 in the flotator, whichever is less.

Figure V-12 has been prepared as a guideline for selecting the appropriate manual control setting as a function of the influent stream turbidity, the chemical feed system characteristics described in Table IV-3, and the recommended dosage ranges noted above.

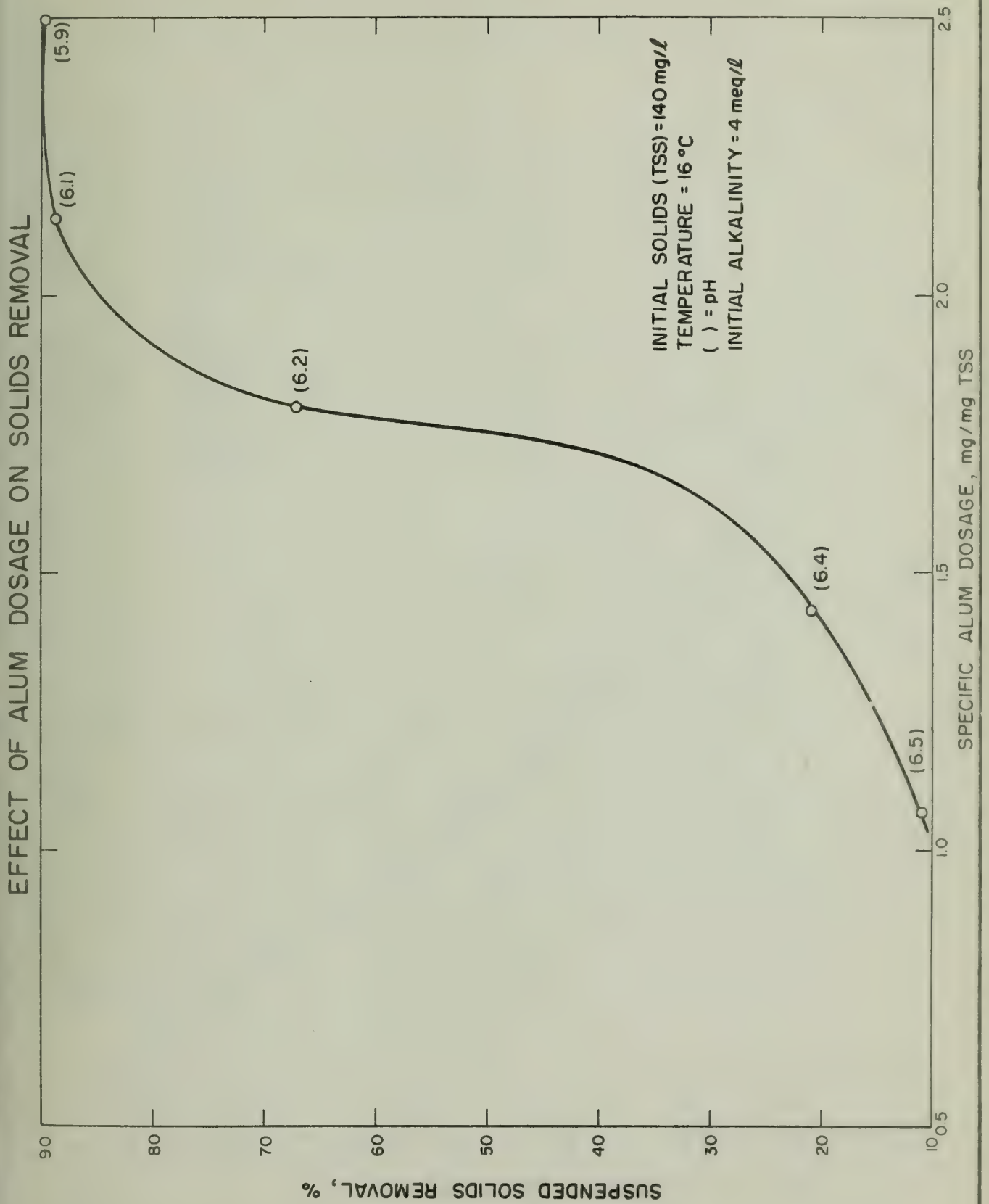
DIURNAL VARIATION OF SUSPENDED SOLIDS CONCENTRATION
BAKER STREET SEWER
(DRY WEATHER AND COMBINED SEWAGE FLOWS)





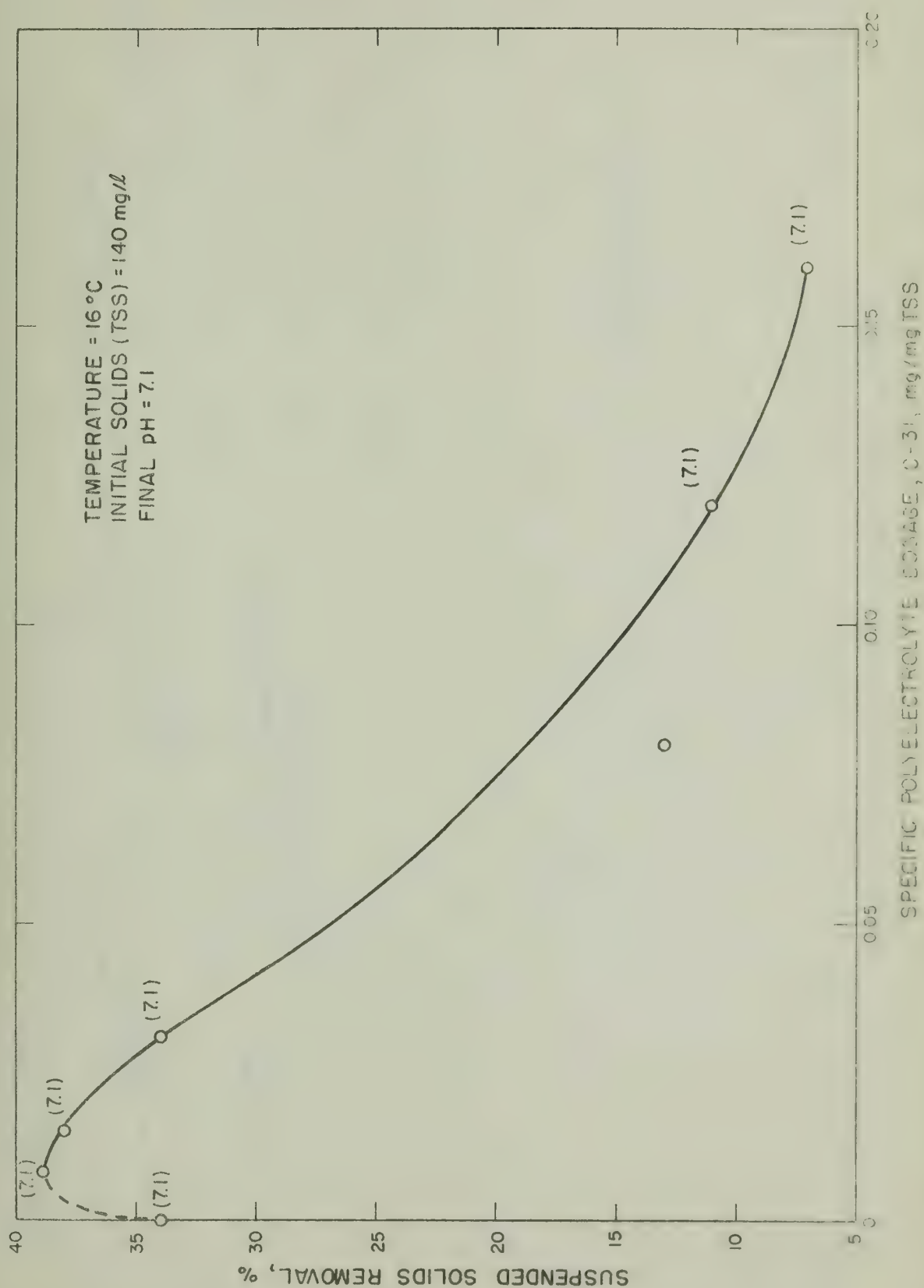






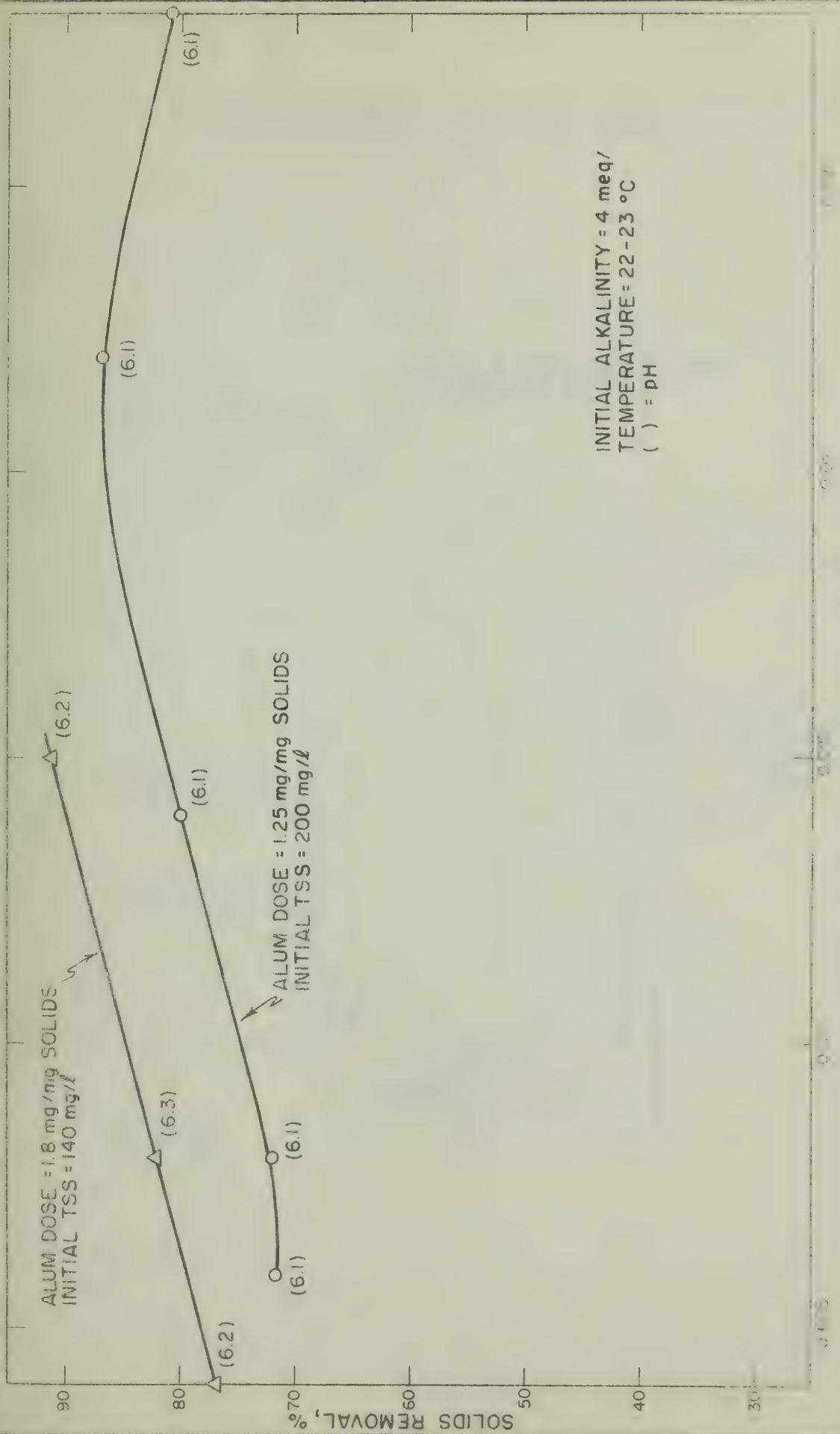


EFFECT OF PURIFLOC C-31 DOSAGE ON SOLIDS REMOVAL





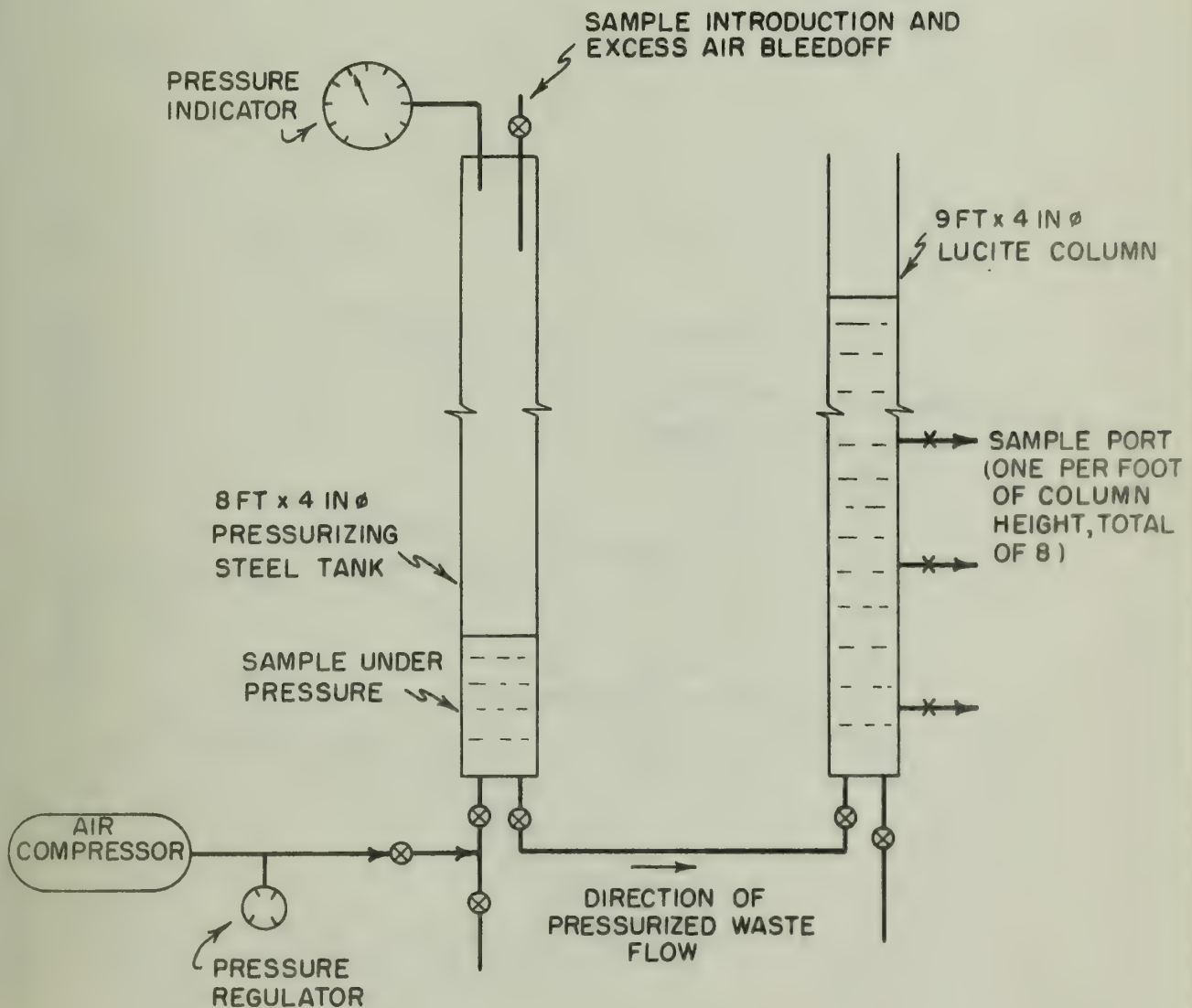
EFFECT OF PURIFLOC C-31 DOSAGE ON SOLIDS REMOVAL AT CONSTANT ALUM DOSAGE



SPECIAL POLYELECTROLYTE DOSAGE, mg/mg solids

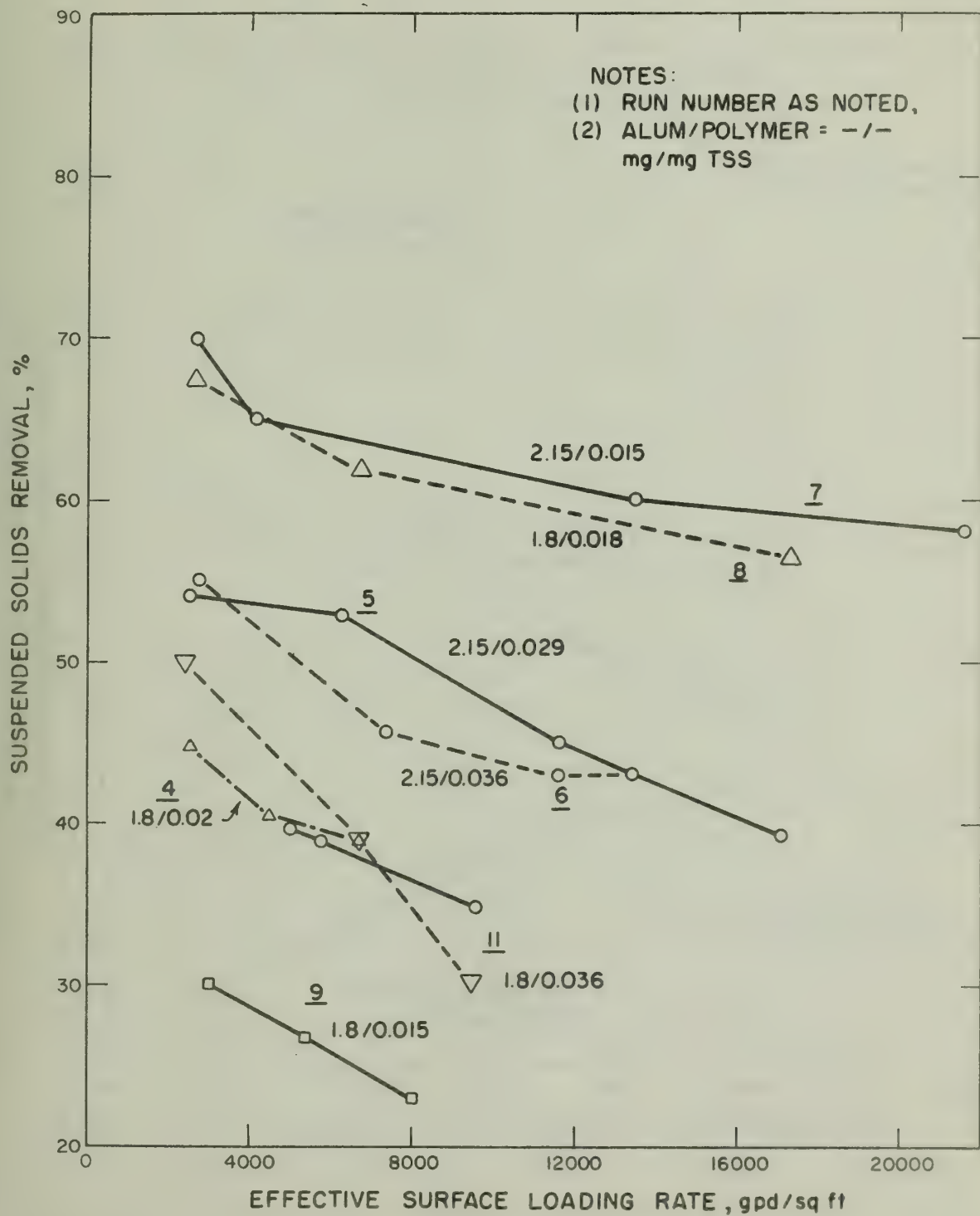


LABORATORY FLOTATION CELL



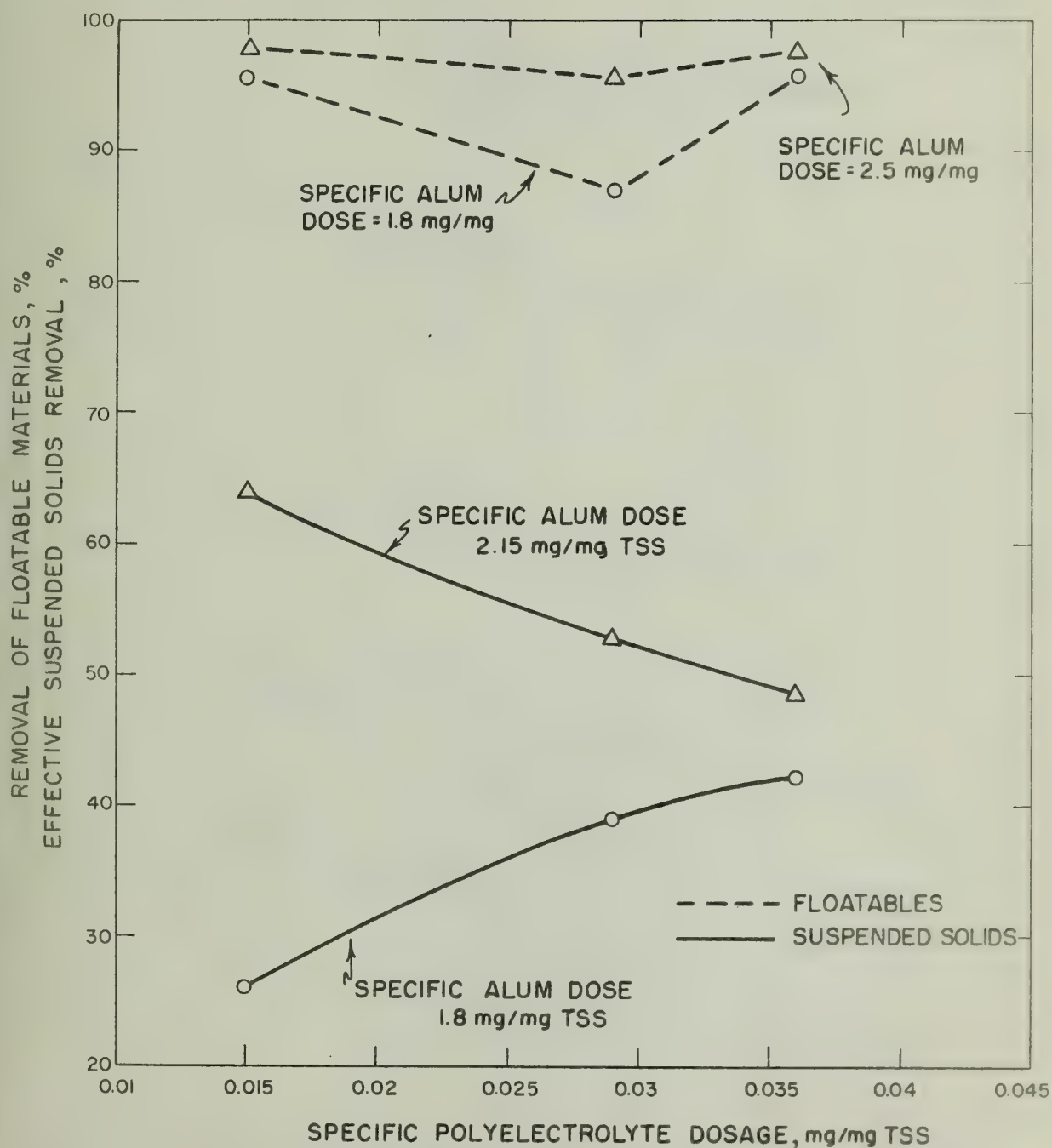


SUSPENDED SOLIDS REMOVAL VS EFFECTIVE SURFACE LOADING RATE LABORATORY FLOTATION CELL TESTS ALUM/POLYMER C-31 TESTS

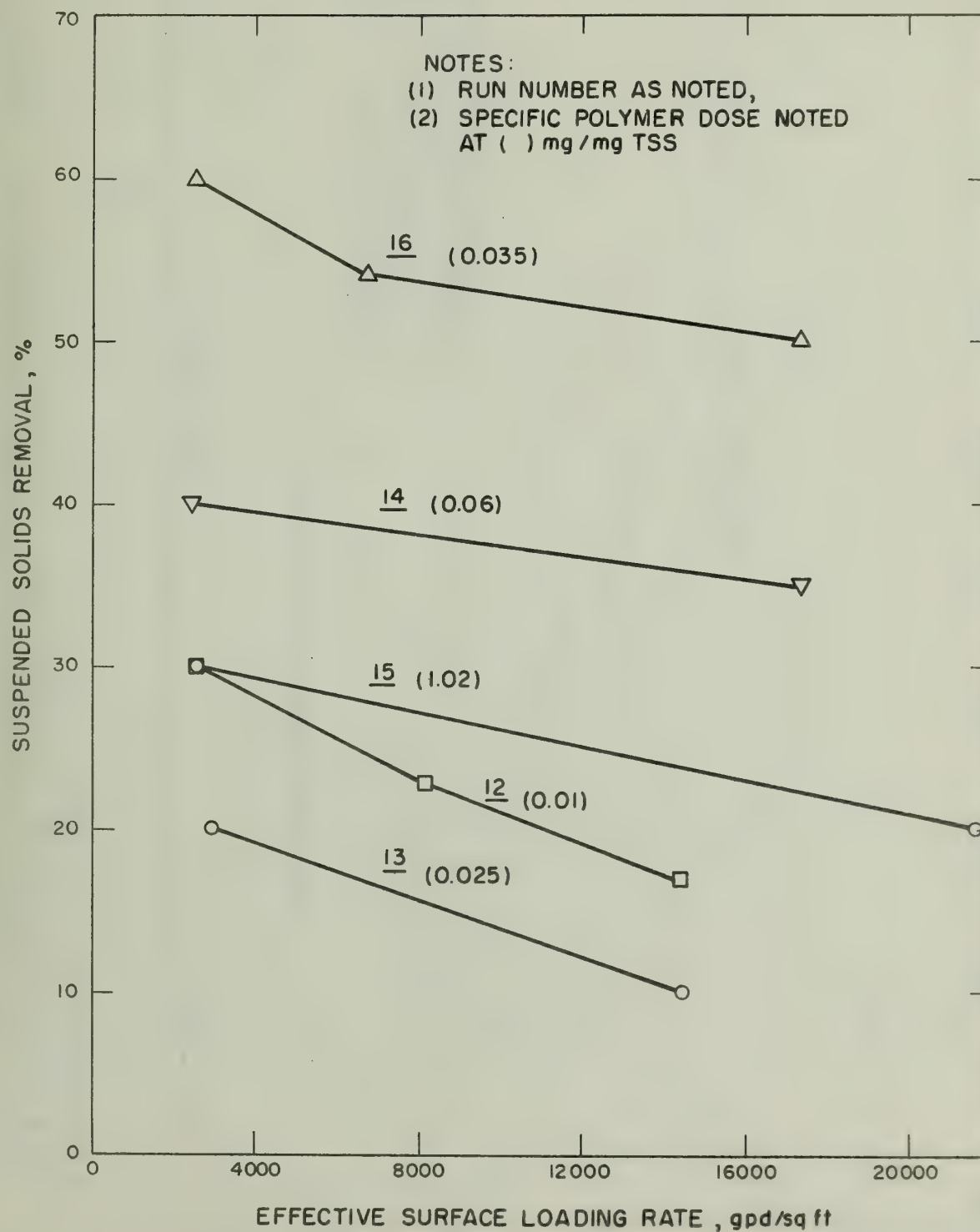




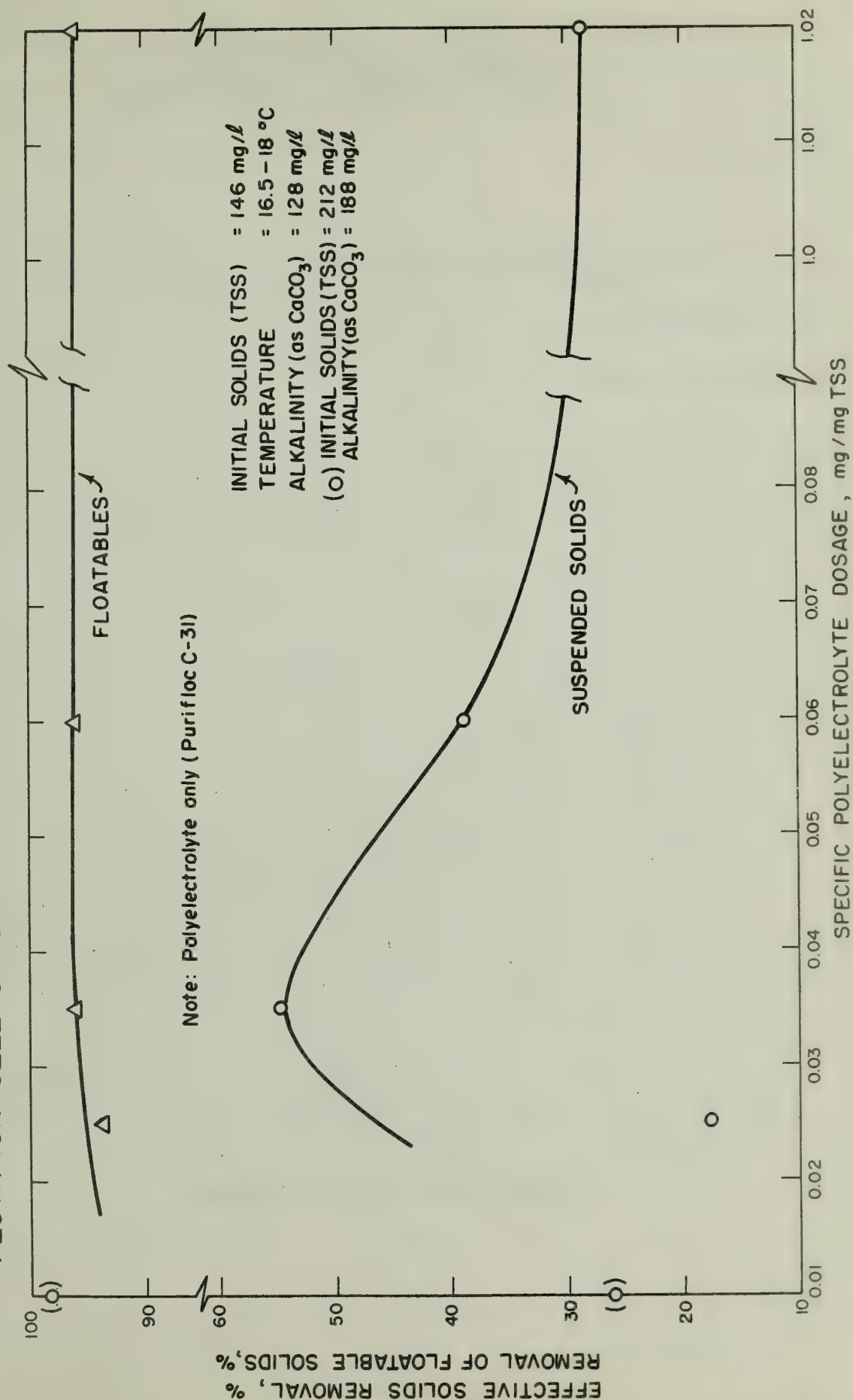
EFFECT OF SPECIFIC POLYELECTROLYTE AND ALUM DOSES
ON SUSPENDED SOLIDS AND FLOATABLES REMOVAL
AT EFFECTIVE SURFACE LOADING RATE OF 6000 GPD/SQ FT
LABORATORY FLOTATION CELL TESTS



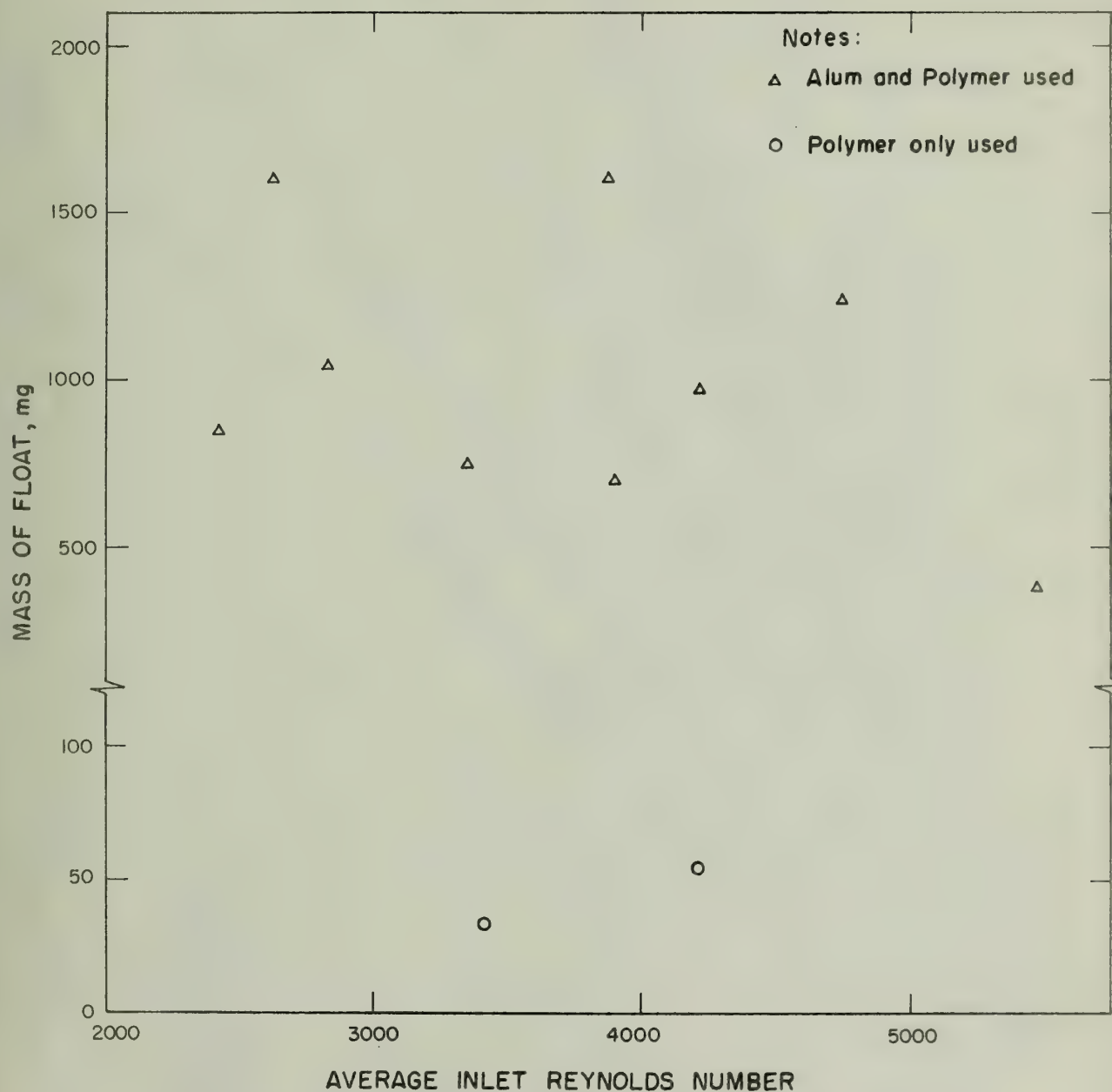
SUSPENDED SOLIDS REMOVAL VS EFFECTIVE SURFACE LOADING
WITH PURIFLOC C-31 AS THE ONLY FLOCCULANT.
LABORATORY FLOTATION CELL STUDY



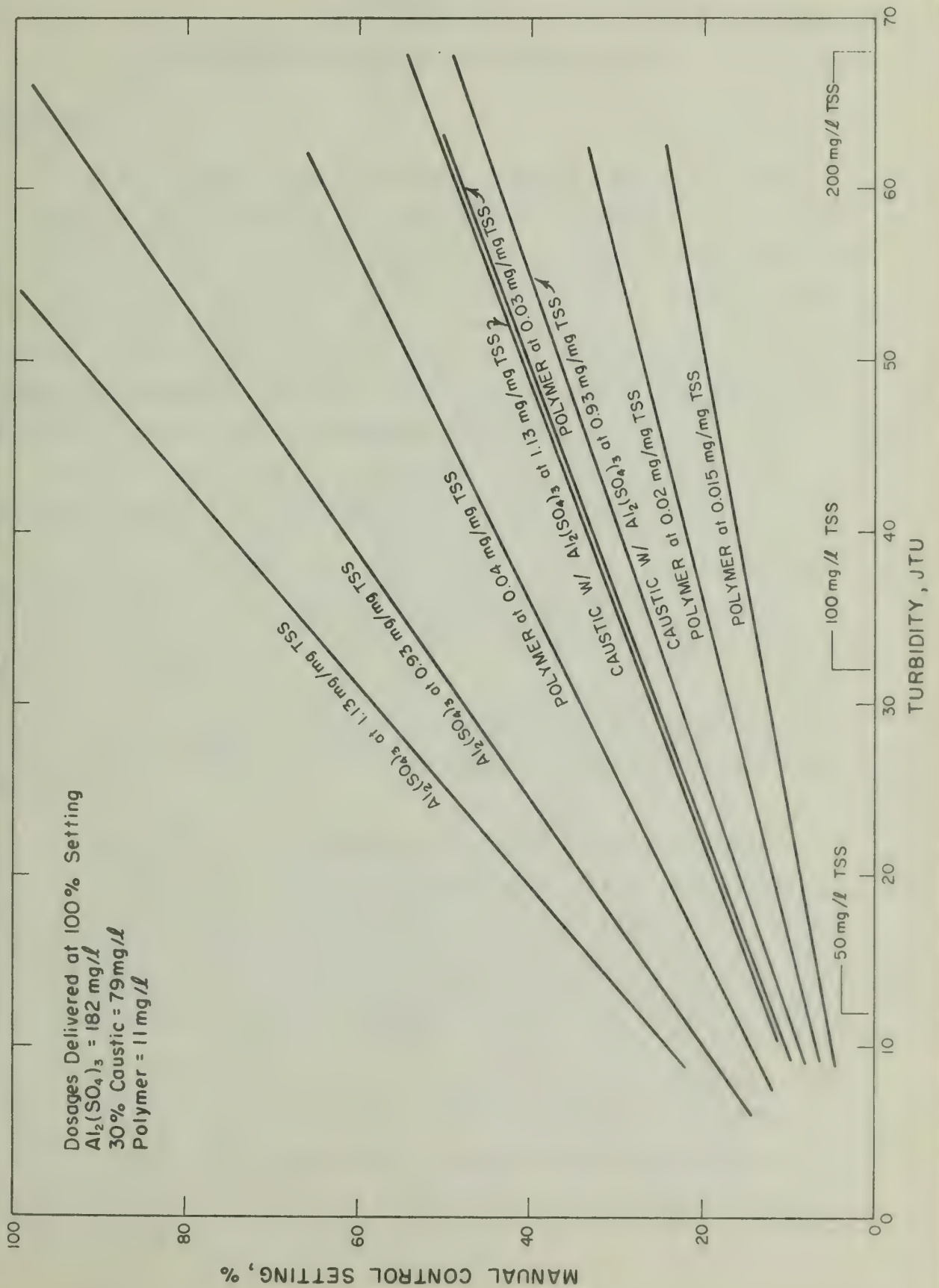
EFFECT OF SPECIFIC POLYELECTROLYTE DOSE ON SUSPENDED SOLIDS REMOVAL AT EFFECTIVE SURFACE LOADING RATE OF 6000 GPD/SQ FT - LABORATORY FLOTATION CELL STUDY



EFFECT OF AVERAGE INLET REYNOLDS NUMBER ON
MASS OF FLOAT FORMED
LABORATORY FLOATATION CELL



MANUAL CONTROL SETTINGS VS INFLUENT STREAM TURBIDITY BAKER STREET DISSOLVED AIR FLOTATION FACILITY



CHAPTER VI

DEVELOPMENT OF FIELD DEMONSTRATION PROGRAM

OBJECTIVES

The general objective of the Phase III demonstration, as stated in Chapter I, was to evaluate the technical and economic efficacy of the dissolved air flotation process for treatment of combined sewer overflows. The present study has sought to develop the information needed to implement this objective by surveying the state-of-the-art of the dissolved air flotation process as a means of identifying specific objectives for how the Baker Street facility should be operated to meet this objective within the limited time and budget framework of the study.

Essentially two types of fundamental relationships, or process performance curves, have been identified in the present study:

(1) Subprocess-dependent relationships, in which the floated and total solids production rates are related to input air:solids ratio, recycle ratio, Reynolds Numbers of flows in the inlet manifold, and liquid and solids loading rates.

(2) System-dependent relationships, in which the floated and total solids production rates are related to skimmer system settings and specific chemical doses.

In view of the implied importance that each of the above relationships was found to have in the literature search, design review, and laboratory studies, the general operating objective selected for the demonstration program was to document each of these relationships for the dissolved air flotation application at Baker Street. The specific objectives of the demonstration program at the Baker Street facility were as follows:

(1) Document the solid, liquid, and air transfers occurring in the dissolved air flotation process as a function of each operating mode.

(2) Document the process-level variables associated with each mode of facility operation, *e.g.*, recycle pump rates, chemical feed

rates, air pressure and pumping rates, and solids handling rates.

(3) Document the influent and effluent characteristics as a function of selected operating mode.

(4) Document the hydraulic characteristics of the components of the facility.

(5) Document the performance characteristics of the facility as a disinfection process.

(6) Document the efficacy of the design used for the Baker Street facility from the operational perspective.

PROGRAM PERSPECTIVE

It is apparent from the foregoing statements that there are two types of questions being considered in the demonstration program--one set of questions relating to confirmation of the general theoretical premises for the dissolved air flotation process, and the second set relating to the development of specific information for how the Baker Street facility should be operated on a routine basis.

It is apparent that the second set of questions can be answered only after a period of operation of the Baker Street facility. However, because of the present state-of-the-art of the dissolved air flotation process, there exists only one approach to answering the former set of questions, *i.e.*, the development of process performance curves such as described in Chapter III. In order to have a general utility, and transferability, the process performance curves must be developed over the range of parameter values necessary to define the saturation, or breakpoint, levels at which process performance ceases to increase for increasing parameter levels. In developing the process performance curves over a sufficient range of parameter variation to identify the saturation, or breakpoint, level, it is essential that a sufficient number of discrete runs be made (the results of each run yielding a single steady-state point) to define the performance curve of concern. That is, the adequate documentation of each of the six fundamental relationships stated at the onset of this chapter will, in each case, require

as a minimum from five to six runs to obtain a sufficient number of points to define the desired process performance curve.

In each case (run), it is necessary that the experiment be conducted under steady-state conditions so that the observed performance is representative of process stability. Steady-state is defined as operation in a fixed mode over a time interval. The suggested initial time criterion for steady-state operation at Baker Street is three hydraulic residence times, until information developed with the 12-point sampling grid is obtained as a basis for establishing that process stability can be obtained in a lesser time interval.

In view of the number and time length of the runs required to document a process performance curve under conditions of process stability, it is apparent that an approach to information development is desirable in which the widest range of parameter variation can be evaluated at the least cost and with the greatest control (traditionally, through several steps of inquiry at the laboratory level), so that the next level of inquiry can deal with a significantly narrower band of parameter variation. Such was the approach used in developing chemical dosage criteria first with jar tests and then with batch flotation cell tests in the laboratory study (Chapter V).

In the process development perspective (be it development of a waste treatment process or any type of process), the next level of inquiry is at the pilot-scale, followed ultimately by the prototype demonstration. The advantages of the pilot-scale level of inquiry prior to prototype design and operation are several:

- (1) Pilot-scale operations can be designed to achieve both controlled loading and operating conditions and operating flexibility.

- (2) Large quantities of information can be obtained rapidly for the development of process performance curves and design criteria for the prototype.

- (3) The information base of the pilot system can be compared with that developed later for prototype operation to establish the scale-up

factors required for extrapolation of pilot-scale performance curves to prototype level in subsequent applications.

(4) The fundamental data base for unit processes should be resident in pilot plant operation, not in unique prototype operations; the successful development of a universal data base is contingent upon compatibility and transferability of pilot plant information.

(5) Without pilot plant information, the boundary values of the prototype cannot be determined other than fortuitously.

It is unfortunate in reviewing the historical perspective of the overall demonstration program that pilot-scale studies were not authorized *a priori* to the construction of the Baker Street facility. The net effect of this necessary omission has been that there exists presently neither an intermediate-scale tool for minimizing the hunt-and-search that will be required in the present program using the Baker Street prototype to develop the process performance curves, nor does there exist a base of data from which scale-up factors can be developed when the prototype is operated. The prototype offers the further disadvantage that, given the hydraulic and quality transiency of combined sewer overflows, there is considerable uncertainty that information developed in prototype operation will be either representative of stable process operation or extensive enough *per se* to permit definition of process performance curves. Additionally, there are several limitations in the prototype relative to measuring floated and total solids production rates and air flow rates individually for each module.

(Pilot plant studies were eventually conducted. Results of that study are presented in Appendix C, Laboratory Data.)

APPROACH

The approach taken in the demonstration program has evolved from a consideration of constraints outlined in previous sections, and represents a commitment to operation of the prototype directly in view of the present unavailability of pilot facilities. As noted previously, the six

relationships of concern are either subprocess-dependent or system-dependent, and it is apparent that a definition is required of the system-dependent relationships before the former relationships can be considered. For this reason the program has been developed as a sequence of six operations as shown below:

- (1) Characterization of hydrodynamic stability.
- (2) Determination of optimal chemical doses.
- (3) Determination of skimmer system characteristics.
- (4) Effect of $(A/S)_1$ on total solids production.
- (5) Effect of recycle ratio on total solids production.

(6) Effect of liquid and solid loading rates and inlet velocity on total solids production.

Each operation will provide sequentially a base of information for decision-making with respect to minimizing the range of variables which must be considered in the subsequent operations. Each operation will consist of at least four runs, or more where necessary, to define the process performance curves of concern.

OVERVIEW OF OPERATIONS

Operation A: Characterization of Hydrodynamic Stability

The objective of this operation is to document the hydraulic throughput characteristics (mean and modal residence times) in the flotation cells over a range of flow rates (Q_1) from 1 mgd per cell to the maximum possible. An overview of the operating variables for Operation A is presented in Table VI-1, and specific variables are noted in Table VI-2. Dye tracer will be injected and samples will be taken at several points with the 12-point sampling grid and at the effluent launder. Both recycle modes will be used to assess the impact of extracting recycle flow from the flotator on the hydraulic characteristics, and a total of five runs is planned.

The information developed in this operation will permit an evaluation of the effect of Q_1 and recycle mode on the level of tank stability

TABLE VI-1

OVERVIEW OF DEMONSTRATION PROGRAM

Operation	Objective	Range of Operating Variables						Recycle Source
		Specific Chemical Doses (mg/mg)		Q _I (mgd/cell)	(A/S) _I	Skimmer System		
		Alum ²	Purifloc C-31					
A	Hydrodynamic Stability	-	-	1.0 - max	-	- ⁴	Varies	
B	Optimize Chemical doses							
	• Alum w/ polymer	1.8 to 2.2	0.015 to 0.020					
	• Polymer alone	-	0.030 to 0.050	5.4	0.05 ³	- ⁴	Flotator	
C	• No Chemical	-	-	5.4	0.05 ³	- ⁴	Flotator	
	Skimmer System Characteristics							
D	• Alum w/ polymer, or Polymer alone	Optimum	Optimum	3.6 to 5.4	0.05 ³	- ⁵	Flotator	
	Effect of (A/S) _I							
	• Alum w/ polymer	Optimum	Optimum					
E	• Polymer alone	-	Optimum	3.0	0.03 to 0.15	Optimum	Influent	
	Effect of Recycle Ratio			3.0	0.03 to 0.15	Optimum	Influent	
	• Alum w/ polymer	Optimum	Optimum					
	• Polymer alone	-	Optimum	5.4	Optimum	Optimum	Varies	
			-	5.4	Optimum	Optimum	Varies	

TABLE VI-1 (Cont'd)

Operation	Objective	Range of Operating Variables						Recycle Source
		Specific Chemical Doses (mg/mg)		Q_I (mgd/cell)	(A/S) _I	Skimmer System		
		Alum ²	Purifloc C-31					
F	Effect of Liquid Loading Rate • Alum w/ polymer • Polymer alone	Optimum						Flotator Flotator
		-	Optimum Optimum	3.6 to max 3.6 to max	Optimum Optimum	Optimum Optimum		

NOTES: (1) Recycle flow constant @ 2.4 mgd.

2 When alum is used, caustic will be used at 1/4 stoichiometric requirements for alum dose.

3 Assumption is that $f = 0.50$, to be confirmed.

4 Set skimmer system at: front depth, 2-in; back depth, 1-in; time interval, 5 minutes.

5 Skimmer system: range of settings

- front depth @ 0 to 2-in
- back depth @ 0 to 1-in
- time interval @ 5 to 30-min

TABLE VI-2
SPECIFIC OPERATIONAL VARIABLES FOR
FIELD DEMONSTRATION PROGRAM

Operation	Run Designation	Specific Variables			
A	A-1	$Q_I = 1 \text{ mgd/cell}$ } Flotator 3 mgd/cell } Cycle 5 mgd/cell } $Q_I = 1 \text{ mgd/cell}$ } Influent $= 3 \text{ mgd/cell}$ } Recycle Chemicals Unnecessary			
	A-2				
	A-3				
	A-4				
	A-5				
B	B-1	Alum:polymer @ 2.2/0.015 mg/mg TSS			
	B-2	Alum:polymer @ 1.8/0.020 mg/mg TSS			
	B-3	Open			
	B-4	Polymer @ 0.035 mg/mg TSS			
	B-5	Open			
C		Q_I (mgd/ cell)	Front Depth (in.)	Back Depth (in.)	Time Interval (min)
	C-1	3.6	2.0	1.0	5
	C-2	3.6	1.0	0.5	5
	C-3	5.4	2.0	1.0	5
	C-4	5.4	1.0	0.5	5
	C-5	Open	Open	Open	Open
D	D-1	Air flow rate @ 4 SCFM } Alum And Polymer			
	D-2				
	D-3				
	D-4				
	D-5				
	D-6	Air flow rate @ 4 SCFM } Polymer Alone			
	D-7				
	D-8				
	D-9				
	D-10				

TABLE VI-2 (Cont'd)

Operation	Run Designation	Specific Variables
E	E-1	$Q_I = 5.4 \text{ mgd/cell}$; flotator recycle
	E-2	$Q_I = 5.4 \text{ mgd/cell}$; influent
	E-3	$Q_I = 5.4 \text{ mgd/cell}$; flotator recycle
	E-4	$Q_I = 5.4 \text{ mgd/cell}$; influent
F	F-1	$Q_I = 3.6 \text{ mgd/cell}$
	F-2	$Q_I = \text{maximum}$
	F-3	$Q_I = 3.6 \text{ mgd/cell}$
	F-4	$Q_I = \text{maximum}$

NOTES: (1) Operation C: all runs with optimum dose of either alum and polymer or polymer alone.

(presence or absence of short-circuiting) as a function of the inlet manifold and effluent launder designs used.

Operation B: Determination of Optimum Chemical Doses

The objective of this operation is to confirm the laboratory-developed chemical dose criteria for polymer when used alone and with alum and caustic. A control run will also be made using no chemicals. Performance will be assessed on the basis of floated and total solids production rates. As noted in Table VI-1, the specific chemical doses to be evaluated are:

- (1) Alum: 1.8 to 2.2 mg/mg TSS.
- (2) Caustic: one-fourth the stoichiometric requirement for alum, or that amount required to maintain a pH of 7, whichever is less.
- (3) Polymer: 0.013 to 0.02 mg/mg TSS when used with alum and caustic; 0.03 to 0.05 mg/mg TSS when used alone.

The flotator cell will be operated at a constant Q_1 level of 5.4 mgd (equivalent to Q of 3 mgd for the modified flow configuration), at a $(A/S)_1$ of 0.06 (assuming $f = 0.50$), and at skimmer system settings noted in Table VI-2. The optimum chemical doses will be selected on the basis of total solids production rates, and a total of five runs are planned.

The optimal chemical doses defined in Operation B will be used in all ensuing operations.

Operation C: Determination of Skimmer System Characteristics

The objective of this operation is to define criteria for the skimmer system settings as a function of the flow rate into the flotator, Q_1 , and flow rate into the module, Q . The effect of skimmer system settings on floated and total solids production rates will be assessed for two front and rear settings at two flow rates, one $(A/S)_1$ ratio, and the optimal chemical doses as noted in Table VI-2. The two flow rates to be used are $Q_1 = 3.6$ and 5.4 mgd. Because the recycle mode will be set to use flotator contents, the above flow rates are equivalent to influent flow rates (Q) of 1.2 and 3.0 mgd,

respectively. A total of five runs is planned for this operation.

Operation D: Effect of $(A/S)_f$ on Floated and Total Solids Production

The objective of this operation is to document the relationships between floated and total solids production rates and $(A/S)_f$ at a constant liquid surface loading rate and recycle ratio, and at the optimum skimmer settings and chemical doses. It is anticipated that the $(A/S)_f$ ratio will be varied between 0.03 and 0.15. The flow rate to the flotator cell, Q_f , will be 3.0 mgd, equivalent to an influent flow rate, Q , of 3.0 mgd when the influent stream is being tapped for recycle (Table VI-2).

The results of this operation will be analyzed to establish the $(A/S)_f$ level at which the maximum floated and total solids production rates can be achieved for the selected experimental conditions. The optimum $(A/S)_f$ level, thus established, will be used as an operating criterion in subsequent operations. A total of 10 runs is planned for Operation D.

Operation E: Effect of Recycle Ratio on Floated and Total Solids Production

This operation will be conducted to assess the relationship between floated and total solids production rates and recycle ratio at the optimum values identified for chemical doses, skimmer system settings, and $(A/S)_f$. The operation will be conducted at a constant flow rate into the flotator (Q_f) of 5.4 mgd and the effect of the recycle ratio will be considered at two recycle ratios--35 percent and 60 percent (Figure IV-5B). A total of four runs will be made in this operation (Table VI-2).

Operation F: Effect of Inlet Velocity on Floated and Total Solids Production

Within the scope of operational flexibility at the Baker Street facility, it is not possible to vary the liquid loading rate independent of the solids loading rate to each flotation cell. Also, the inlet velocity (and Reynolds Number) of the inlet flow to each flotation cell is directly proportional to the liquid loading rate. As a result, it is possible to evaluate the effect of these variables

on total solids production only on a simultaneous basis. Within this perspective the objective for Operation F is to assess the impact of varying the liquid loading rate, or flow rate Q_l , into the flotator cell, on the total solids production rate. The operations will be conducted at optimum levels of chemical doses, $(A/S)_l$'s, and skimmer system settings, and over a range of Q_l values from 1.0 mgd/cell to the maximum flow rate attainable. The selected experimental conditions will also permit the examination of process performance over a wide range of inlet velocities and solids loading rates. A total of four runs will be made as noted in Table VI-2.

The results of this operation will be analyzed to establish (1) the liquid loading rate at which the maximum floated and total solids production rates can be achieved, and (2) the general relationships between liquid loading rates, solids loading rates, and Reynolds Numbers of the inlet manifold flows and the floated and total solids production rates.

ORGANIZATION OF OPERATIONS

Scope

Each of the previously described operations will consist of a sequence of four or more runs, each run being defined by a specific set of valve and control settings, and the total number of runs per operation being the minimum necessary within the time, budget, and storm runoff available to define the relationship of concern. A total of 33 runs has been planned as described in Table VI-2.

Information Requirements

Process characterization will require development of the following types of information for each run:

(1) Material balances for total suspended solids and HEM (hexane extractable material), for liquid transfers, and for air transfers.

(2) Influent characterization of turbidity (for control of chemical dosage rate), coliform MPN, total suspended solids, HEM, floatable materials, and other characteristics as defined in the sampling and analytical program (Table VI-3).

TABLE VI-3
SCHEDULE OF ANALYSIS

Characteristics	Sampling Location and No. of Samples to be Analyzed per Operation				
	Facility Influent	Flotation Cell (12)	Facility Effluent	Float	Solids
COD	10	-	10	-	-
BOD*	5	-	5	-	-
Floatables	10	12	10	3	-
Oil & Grease (HEM)	10	12	10	3	6
Settleable Solids	10	12	10	-	-
Nitrogen Forms	5	-	5	1	6
O-Phosphate	5	-	5	1	6
TSS & VSS	10	12	10	3	6
Total Solids	-	-	-	3	6
Conductivity	10	-	10	-	-
Alkalinity	10	-	10	-	-
Total Coliform MPN*	10	-	10	-	-
Fecal Coliform MPN*	10	-	10	-	-
Cl ₂ Residual or Demand*	-	-	10	-	-
Toxicity	5	-	5	-	-
Productivity	1	-	1	-	-
pH	10	-	10	-	-
Color	2	-	2	-	-
Turbidity*	10	36	10	-	-
Maximum No. of Samples per Operation Subjected to Analysis	10	36, or 3X @ 12 points	10	3	3

* Analysis to be made or set up at Baker Street facility.

(3) Process-level variables: recycle pump rate; chemical feed rates; air pressure and transfer rates; float characteristics; solids transfer rates from the solids handling sump; skimmer system settings; etc.

(4) Facility operations tracking: instrument calibrations; power costs; and water requirements.

(5) Hydraulic flow-through characteristics of flotation cells.

(6) Profiles of concentrations of total solids, suspended solids, floatables, HEM, and settleable solids in the flotation cell.

In order to acquire this information, time-correspondence sampling will be required at the following points during the course of a run:

(1) Influent and effluent streams.

(2) Solids sump.

(3) Float in the skimmer system.

(4) Twelve-point sampling grid on the flotation cells.

The data to be logged on a time-correspondence basis with the above sampling will include:

(1) Module flow integrator readouts.

(2) Module flow rate and flow controller readouts.

(3) Flotator cell water levels.

(4) Solids handling pump flow integrator readout.

(5) Chemical storage tank levels.

(6) Manual control settings for all chemical feed pumps.

Sampling and Analysis Program

Sampling Protocol

The following sampling protocol will be used for each run:

(1) Influent sampling will be conducted at the inlet structure between the inlet gate and bar screen and:

(a) One sample will be taken after the low level probe at Baker Street and Marina Boulevard is tripped.

(b) Samples will be taken every 15 minutes after the inlet opens.

(2) Effluent samples will be taken from access ports to the west and east module effluent launders located in the equipment room. Samples will be taken every 15 minutes after the level in the flotation cell rises to the 10-ft level as indicated on the control panel.

(3) The solids sump will be sampled at the inspection port on the control room flow, and:

(a) The initial samples will be taken as the inlet gate is opened.

(b) Samples will be taken thereafter at 15-min intervals after the recycle system is activated.

(4) Floats in the skimmer systems of the west and east modules will be sampled at half-hour intervals from taps on the scum lines just upstream from point of entry of the lines to the solids sump.

(5) The ports on the 12-point sampling grids of the west and east modules will be sampled at 15-min intervals after the level in the flotation cell rises to the 10-ft level as indicated on the control panel.

Analytical Program

A schedule of the analyses to be performed on each of the five sample types identified above is shown in Table VI-3. In view of the budgetary constraints, it has been necessary in the analytical program to limit the maximum number of samples of each type that can be given complete analysis, and to minimize the replication of some of the more expensive types of analyses during a run. The scope of the analytical program noted in Table VI-3, while closely defined, is intended to be flexible and to serve as a guideline for how much identifying analytical effort can be expended per operation.

The selection of which specific sample(s) of a given type will be subjected to the partial and the complete analytical schedule will be

made after a review of operating logs for the runs of concern and a consideration of other prior information. The settleable solids, turbidity, and chlorine residual or demand analyses noted in Table VI-3 will be done at the Baker Street facility. The BOD and total coliform MPN analyses will be set up at the facility and completed offsite, as will all other analyses. It is recommended that the entire analytical program be subject to review after the initial operations to assess the efficacy of the program and to permit timely adjustment in scope as deemed necessary.

CHAPTER VII

REFERENCES

1. Vrablik, E. R., "*Fundamental Principles of Dissolved-Air Flotation of Industrial Wastes*", Proceedings 14th Purdue Industrial Waste Conference, 743-779, (1959).
2. Ettelt, G. A., "*Activated Sludge Thickening by Dissolved Air Flotation*", Proceedings 19th Purdue Industrial Waste Conference, 210-244, (1964).
3. Hansen, C. A. and Gotaas, H. B., "*Sewage Treatment by Flotation*", Sewage Work Journal, Vol. 15 (2), 242-254, (March 1943).
4. Eckenfelder, W. W., Jr., Industrial Pollution Control, pp. 52-62 New York, McGraw-Hill, 1966.
5. Mason, Donald G., "*The Use of Screening/Dissolved Air Flotation for Treating Combined Sewer Overflows*", Presented at symposium on Storm and Combined Overflows, June 22-23, 1970, Chicago, Illinois.
6. "*Engineering Report on Preliminary Design-Marine Sewage Disposal System for Rio de Janiero*", prepared by Engineering-Science, Inc., for SURSAN, Rio de Janiero, GB, Brazil (June 1969).
7. Mulbarger, M. C. and Huffman, D. D., "*Mixed Liquor Solids Separation by Flotation*", Journal SED, ASCE: 96 (SA4), 861-871, August 1970.
8. Katz, W. J. and Geinopolos, A., "*Sludge Thickening by Dissolved-Air Flotation*", JWPCF:39 (6), 946-957, (June 1967).
9. "*Phase I: Pre-Construction Studies on Quantity and Quality Relationships of Combined Sewage Flows and Receiving Water Studies at Outer Marina Beach*", submitted by Engineering-Science, Inc., to City and County of San Francisco, April 1970.
10. Shea, T., unpublished data, "*Laboratory Flotation Studies*", March 1969.
11. "*Analysis of Improved Suspended Solids Removal at the Existing Sewage Treatment Facility*", prepared for the City of Pacific Grove, California, by Engineering-Science, Inc., June 1970.

APPENDIX A

PHYSIOCHEMICAL MECHANISMS IN DISSOLVED AIR FLOTATION PROCESS

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PHYSIOCHEMICAL MECHANISMS IN DISSOLVED AIR FLOTATION PROCESS

FRAMEWORK

A starting point for inquiry into the scope of mechanisms in the dissolved air flotation (DAF) is presented in Figure A-1. Dissolved air flotation in the context of sewage treatment is a unit process for the separation from a liquid of particulates or soluble materials converted to particles as described in Chapter II. The separation process involves the interplay of a number of mechanisms that affect the clarification of the liquid phase.

Solids Character

The first level of inquiry in Figure A-1 relates to whether the solids in a liquid are discrete, dissolved, or colloidal. The character of solids in a sewage effluent will be affected by pretreatment unit processes (Reference A-1) that serve to:

(1) Convert (by the mechanism of flocculation) colloidal particles into discrete solids.

(2) Convert dissolved solids components by the mechanism of coagulation and precipitation into discrete solids.

The type and extent of chemical pretreatment can determine in turn the concentration of discrete solids potential available for treatment by flotation. The alternatives for location of chemical addition at the Baker Street dissolved air flotation facility are discussed in Chapter IV.

The second level of inquiry in Figure A-1 relates to whether or not the discrete solids are inherently floatable, in which case removal can be accomplished without mechanical means. If the discrete solids are not inherently floatable, it is then necessary to consider (in terms of the dissolved air flotation process) whether or not an air-discrete solid aggregate can be formed. If the latter cannot be formed, the the dissolved air flotation process cannot be used to effect removal of the solids. However, if an air-discrete solid aggregated can be formed with the particles of concern, attention can then be directed to the

basic rate-limiting steps in the process of aggregate formation (bubble formation, transport, attachment) and to the mechanisms known to be operative in each of these steps.

MECHANISMS IN AGGREGATE FORMATION

The formation of air bubbles in the dissolved air flotation process can occur in one of three ways (References A-2, A-3, and A-4):

- (1) Formation of a single bubble that rises to the top of the fluid.
- (2) Coalescence of large bubbles with smaller bubbles which then rise to the top.
- (3) Formation of aeroflocs by entrapment of gas bubbles within flocs.

Each of these modes of aggregate formation is illustrated in Figure A-2. The types of mechanisms operative and their ramifications can be considered in terms of bubble formation, transport, or attachment mechanisms controlling the rate of aggregate formation.

Bubble Formation

Bubble formation depends on *the method and device used for bubbling, time of bubble formation, material and texture of the aperture, shape of the aperture, arrangement of apertures, and the physiochemical conditions of the liquid phase* (Reference A-5). The shape of a bubble and its size depend on the mode of formation height of fluid column, gas flow rate, surface energy of the fluid, viscosity and the quantity and quality of impurities.

The most significant of the physiochemical conditions of the liquid are:

- (1) The hydrostatic pressure (H) which is a function of height and density of the fluid above the tip of a capillary.
- (2) The back-pressure (p) due to surface tension, which is a function of the radius of the bubble and the surface tension at the gas-liquid interface.

In equation form, the capillary pressure is equated with surface tension as follows:

$$p = \frac{2\sigma}{r} \quad (A-1)$$

where: p = capillary pressure (dynes)

σ = surface tension at the interface liquid/gas (dynes/cm)

r = radius of bubble (cm)

Mancy *et al.* (Reference A-2) have further indicated that bubbling begins when the total gas pressure P exceeds $(H+p)$. Once formed, the bubble must be able to withstand the hydrodynamic effect of the circulating fluid which strains the wall of the bubble and causes it to shear and perhaps split as it rises.

Gas bubbles in the dissolved air flotation process can be obtained either by mechanical shear or other means in dispersed air flotation and by precipitation of a gas from a solution supersaturated with the gas in dissolved air flotation. Bubbles of 1,000 microns in size are obtained generally in dispersed air flotation; whereas, bubbles of 80-micron size can be obtained in the latter process (Reference A-2). Klassen *et al.* (Reference A-4) have reported that the most efficient flotation of minerals was obtained when the relative size distribution of particles and air bubbles were approximately identical.

Transport-Controlled Aggregate Formation

The bubble formed in the liquid column rises to the liquid surface carrying with it solid particles. The formation of the bubble-solid particle aggregate and the subsequent removal of the solids can be caused by a number of transport phenomena. The transport mechanisms that can be variously at work in flotation (Figure A-1) are impaction (molecular forces), interception, and brownian diffusion.

Impaction

In an idealized picture of the fluid-bubble medium, the suspended particles subjected to the viscous forces of the fluid will follow fluid streamlines. Impaction defines the situation when the inertia of the suspended particles is such that they do not follow the bending fluid streamlines when approaching an obstacle but tend to continue in the original direction of flow. This would increase the probability of contact between a bubble in the fluid and a particle (Reference A-7).

Philipoff and Evans in 1952 postulated a *bounce theory* which considers that a particle, because of its inertial force, will leave a streamline and bump into the surface of a bubble (Reference A-8).

Interception

If the fluid streamline is such that the particle is within a distance equal to or less than the bubble radius, then contact will be made. This is a transport mechanism and a collision between a suspended particle and gas bubble does not imply attachment.

Molecular Forces

The surface of a fluid differs from the interior phase because there is not a complete balance of inter-molecular forces at the surface. In the interior every molecule of the fluid is completely surrounded by other molecules. At the surface, the forces of attraction on a molecule are only on one side giving rise to a tension force (surface tension) at the fluid surface. Wark has shown that the forces holding a particle to a bubble in flotation process depend upon the surface tension and the contact angle (Reference A-8).

Brownian Diffusion

As particles are removed from the fluid with rising bubbles, a concentration gradient will develop between the fluid surface and the bulk of the liquid. It has been established that the mass flux of suspended solids is proportional to this concentration gradient, and that Fick's first law of diffusion [mass flux = $D_{bm}(dc/dx)$] is applicable to this system where D_{bm} is the coefficient of concentration gradient in the x direction. The coefficient of brownian diffusion is inversely proportional to the particle size; thus, for colloidal particles, brownian diffusion may be a significant transport mechanism (Reference A-6). Colloidal solids in a sewage effluent may represent a minor portion of the fluid mass but may account for a large portion of the total solid surface present so that a consideration of colloidal properties is important.

Wark (Reference A-8) has indicated that a fundamental characteristic of colloidal solution is that the particles of the suspended matter,



through not completely in solution, are not large enough to settle. They remain in suspension because of brownian movement which means that they are subjected to an unbalanced buffeting by the individual molecules of the suspending liquid.

Attachment-Controlled Aggregate Formation

Gaudin has reported that the extent to which encounters of bubbles and particles occur is impossible to determine exactly in a complex system such as an aerated pulp. It can, however, be analyzed when the factors that govern particle bubble attachment are understood. Gaudin (Reference A-6) assumed that water was a perfect liquid, and the particle and bubble are spherical, and the aggregate moves vertically with uniform velocity, and showed that encounters will take place between bubble and particle if they are vertically above each other. This does not indicate the possible mode of attachment after the encounter, which may be governed by electrostatic, electrokinetic, molecular, or chemical forces.

Electrostatic Forces

A solid in contact with a liquid acquires a surface charge. The nature and origin of this charge depends on the solid; and may be due to dissociation of inorganic groups, charge transport across the interface by ions common to the solid lattice, specific adsorption of electro-potential-determining ions, deformation of polarizable ions on the surface, or other causes. To satisfy the condition of electroneutrality, an equivalent amount of ionic charge of opposite sign to that of the particle is distributed on the liquid side of the solid-liquid interface forming an electrical double layer.

Vrablik (Reference A-2) has observed that air bubbles are negatively charged due to ion pairs, the anions generally predominating on the gas side of the interface, with the cations as a diffuse layer on the water side of the interface. As suspended particles or globules may have appreciable surface charge, there may be either attraction or repulsion between the solid particles and gas bubbles. Wark (Reference A-8) has reported that it was thought that a suitably conditioned particle bore a charge of opposite sign to that of the air bubble and that the

attachment was due to the attraction between these unlike charges. Wark concluded that this concept has not been verified by experiment but that electrical forces are not without influence in flotation.

Klassen *et al.* have taken a firmer position in this area, and have emphasized the importance of the polarity of substances in flotation (Reference A-4). They indicated that the polarity of substances is determined by nature of composition and structure of the substances. If bonding atoms of a substance have identical electronegativity, the polarity disappears. The greater the difference in electronegativity of atoms, the higher is the polarity of the substance. Molecules of polar substances are capable of exchanging electrons with other molecules because of their asymmetrical structure. Water has a unique dipole (polar) structure which must be considered in the dissolved air flotation phenomenon. Ions can attract other ions of opposite charge and also electrically neutral bodies or polar molecules. The polar molecules orient themselves in such a way that their charge, opposite to that of the ion, is directed towards the ion.

Electrokinetic Forces

It has been noted that a charged particle is surrounded by an atmosphere of ions of opposite sign to the surface charge. The electrokinetic or zeta potential is the property upon which migration of the particle in an electrical field depends. When there is relative motion between a liquid and a solid, the double layer or a portion of it is continuously sheared away. A charge particle, moving in this liquid, carries with it a thin film of the liquid molecules, the whole forming the electrical double layer. The potential difference between the outer surface of the accompanying liquid film and the bulk of the liquid is defined as the electrokinetic potential. The motion of the particle in an applied electrical field is dependent upon this. Agrawal (Reference A-9) has hypothesized that the electrokinetic potential is in itself a significant factor in the transport and attachment of the particle to the receiving surface. Wark (Reference A-8) has noted that when an air bubble attaches itself to a solid particle, the whole of the liquid film is displaced from the portion of the surface, and consequently, the whole of the electrical double layer disappears. Agrawal has further stated that the

extent of the electrical neutralization during the collapse has not yet been documented, and therefore, one cannot decide which of the potentials is significant in flotation. Some investigators have attempted unsuccessfully to determine the effect of electrokinetic potential on flotation by measuring electroosmosis and electrophoresis.

Chemical Forces

Most investigations of solids separation phenomena have tended to ignore the importance of chemical forces which result from surface interactions such as ion exchange, hydrogen bonding, and the formation of coordinate bonds and linkages. These interactions are not expected to have any significant influence on the separation of discrete particles in the absence of chemical coagulations. However, if inorganic or organic coagulants such as alum, iron, or polyelectrolytes are present in, or added to, the influent water, then chemical interactions may be significant in attaining particle removal. The chemical forces resulting from these chemical interactions have not been definitely identified; nor has any attempt been made to assess quantitatively the effects of the chemical forces on the flotation operation. Therefore, the following considerations on chemical forces are only qualitative in character.

Hydrophobic colloidal particles can be coagulated by adding metallic ions, usually aluminum or iron, to the dispersion. Coagulation is accomplished by reducing the repulsive forces between the particles until the attractive forces dominate the system and the particles coagulate. The mechanisms bringing about coagulation are related to changes which can be attained in the Nernst, Stern, and zeta potentials by manipulations of the hydro-chemical environment. However, the destabilization of colloiddally-dispersed solids by polyelectrolytes cannot be explained entirely by the double layer and other concepts utilized to explain the behavior of hydrophobic colloids. Several researchers have interpreted this latter type of colloidal destabilization as a process of adsorption of polymers on the surface of colloids followed by the bridging of the polymer chains between colloidal particles. Stumm and Morgan (Reference A-15) have suggested that this same phenomenon may occur when inorganic chemicals are used as coagulants. Ionic forms of aluminum and iron when placed in an aqueous environment form hydroxo-metal complexes which behave in a

manner similar to the organic polyelectrolytes.

Evaluation of Mechanisms

The mechanisms which may be responsible for particle-bubble attachment, transport, and removal have been discussed. They include interception, impaction, molecular forces, brownian diffusion, electrostatic forces, electrokinetic forces, and chemical forces. There is no theoretical basis or data at present to indicate that one mechanism is specifically responsible for solids removal in flotation.

HYDRODYNAMICS

Brown (Reference A-10) has reported that theoretical and experimental studies on flotation in the laboratory have been concentrated on simpler flow conditions with the result that only a few general conclusions can be applied to practice. Brown has noted that the important forces to be considered in the particle-bubble collision process included hydrodynamic forces. This collision is said to occur probably under turbulent flow conditions in actual flotation machines.

The role of hydrodynamics has not been fully explored in flotation. Hydrodynamic mechanisms may be operative in the following processes:

- (1) Mixing caused by air bubbles in the flotation tank.
- (2) Generation of shear fields as the bubbles rise to the top of the flotation tank.

Work by Ettelt *et al.* (Reference A-11) has shown that adhesion efficiency (ratio of effective air:solids ratio to input air:solids ratio) is a function of the hydrodynamics of pressurized fluid inlet as related to shear of air-particle aggregates. Ettelt used the Reynolds Number to quantify the hydrodynamic state of the flow regime.

PARTICLE SHEAR

Not much has been written on the role of particle shear in dissolved air flotation. However, most investigators contend that the greater the aeration intensity (as measured by an input air:solids ratio), the higher the shearing stresses to which the particles of concern (*i.e.*, air-discrete solid aggregates) are subjected.

Particle Character

Particles can be described as either discrete or aggregate as a function of how they were formed. Many of the types of particles found in water and wastewater are discrete (such as a fragment of wood); whereas, processes such as chemical or biological flocculation produce aggregate particles. The strength of the particle can be defined as its ability to withstand shearing stresses imposed on it in a shear field such as is believed to be generated with the flow of liquid through the microscreen process. Based on the limited body of information in the literature, the major consideration of particle shear has been with aggregate rather than discrete particles. The emphasis in subsequent discussions is placed on floc strength of particle aggregates (flocs) produced in the chemical pretreatment of aqueous streams; but, because of the aggregate nature of biological floc, is applicable in a general sense to all aggregate particles.

Significance of Floc Strength

Flocs formed by the addition of coagulants to an aqueous system are the result of a complex series of events, both physical and chemical, which involve the properties of the solvent (water), the solute (ions, organic materials, colloids, and particulates), and coagulant. Initial floc formation (primary floc) is primarily a chemical phenomenon, consisting of charge neutralization and aggregation through collisions brought about by brownian motion, which is a dominant mechanism for aggregation until the flocs reach a size of approximately 0.1 micron. Thereafter, velocity gradients generated by mixing devices or other means of energy input effect further collisions between the primary flocs, causing the formation of larger aggregates designated as secondary flocs (Reference A-16).

The bonding forces within the primary flocs are considered to be stronger than the bonding forces between primary flocs. When the applied shear stress is greater than the cohesive force of an aggregate floc, the floc will be fragmented into smaller floc. The practical upper size limit for coagulant flocs in water treatment facilities is in the range of 100 to 2,000 microns, and for a given situation this upper limit is determined by the cohesive forces between primary flocs making up the

secondary floc and shearing stresses imposed on the floc by velocity gradients in the fluid medium.

Effect of Floc Strength and Aggregate Shear in Flotation Processes

The factor of major concern in the operation of flotation processes relates to the effect of floc strength on the integrity of air bubble-particle aggregates, or at a more general level, on the adhesion efficiency as defined by Ettelt (Reference A-11). The attachment of air bubbles to discrete solids is due to the transport of these pairs to a point of attachment. Because strong floc implies a strong cohesive force, the efficiency of attachment is expected to be greater for stronger flocs (such as obtained with alum) than for weaker flocs.

Aggregate shear in the flotation process has been identified as a factor of significant concern in the design of pressure-reducing systems and flotator tank inlet structures and in the use of pumpage (Reference A-12). Aggregates traversing these sectors are subjected to shear forces in the shear fields generated as flow is passed (or pulled) through, and Ettelt has presented evidence (discussed in Chapter III) to document the limiting effect of turbulence on floated solids production.

MECHANISMS IN SOLIDS SEPARATION AND THICKENING

Solids Separation

Solids separation by sedimentation or the dissolved air flotation process applies to those operations in which a suspension is separated into two output streams, a clarified liquid and a more concentrated suspension. Sedimentation can relate to clarification, where primary interest lies in the clarity of the water, and thickening, where primary interest lies in the concentration of the underflow. Normally the quality of the output streams is optimized in terms of either the clarified supernate or the underflow, with economic evaluation of the process output done in terms of the specific output of interest.

Mechanisms

Suspended solids may settle in any of four different ways, determined primarily by the concentration of the suspension and the flocculating properties of the particles. The effect of these factors on the settling

regime is indicated in Figure A-3. Class I clarification applies to dilute suspensions of particles which exhibit no tendency to coalesce on contact. In extremely dilute solution these particles will settle essentially in an unhindered manner. Only when such particles occur in high concentration does the situation arise in which zone settling and/or compression is a possibility. Such a situation might occur at, or near, the bottom of a clarifier, or in the zone of float formation in a flotator.

Class II clarification (Figure A-3) applies to particles which will adhere to one another on contact. In dilute suspensions, where the probability of solids flocculation is low, the individual particles may show little tendency to settle. As concentration increases, flocculent particles will tend to form and subsequently settle as discrete but flocculated particles. These particles are much more likely to undergo zone settling and compression than Class I particles. The concentrations required to produce these latter conditions may be due to the initial solids concentration of the suspension or to the solids concentrations developed by the settling process.

Zone settling is applicable characteristically to the settling of mixed liquor solids when the solids concentration exceeds 500 mg/l. The settling process is distinguished by three zones, as shown in Figure A-4. During an initial settling period, sludge settles at a uniform velocity which is a function of the initial solids concentration (Figure A-4). As settling proceeds, the collapsed solids on the bottom zone (at concentration D) of the settling unit build up at a constant rate. C is a zone of transition through which the settling velocity decreases as the result of an increasing concentration of solids. The concentration of solids in the zone settling layer remains constant until the settling interface approaches the rising layers of collapsed solids (inset III, Figure A-4), and a transition zone C occurs. Through the transition zone, the settling velocity will decrease because of the increasing density and viscosity of the suspension surrounding the particles. When the rising layer of settled solids reaches the interface, a compression zone D (Inset IV) occurs (References A-12 and A-13).

Thickening

Katz *et al.* have noted that the use of dissolved air flotation as a means of dewatering wastewater treatment plant sludges is a recent occurrence (Reference A-14). Sludge thickening is advantageous in reducing sludge volume and evaporation costs. The authors point to the hydrophilic nature of biological slimes obtained from secondary wastewater treatment processes, and indicate that these sludges are the most difficult to dewater. Thickening by sedimentation without chemical aids has in most cases not achieved concentrations of activated sludge greater than two percent. Dissolved air flotation has been found more efficient for the dewatering of biological sludges for it yields greater solids concentrations than plain sedimentation.

Summary

The dissolved air flotation process encompasses various mechanisms. The impact of most of these mechanisms on the performance of the dissolved air flotation process is not yet fully understood, but qualitative assessments of these mechanisms can be found in the literature. The most significant factor emerging from this evaluation is that the formation and preservation of the air-discrete solid aggregate is the most important single factor in the successful application of the dissolved air flotation process.

APPENDIX A - LIST OF REFERENCES

CITED REFERENCES

- A-1 Chapter IV of *"Unit Processes and Processing Alternatives for Treatment of Concentrated Waste Streams"*, report by ES to FWPCA, November 1969.
- A-2 Vrablik, E. R., *"Fundamental Principles of Dissolved-Air Flotation of Industrial Wastes"*, Purdue Ind. Waste Conf., 743-779, (1959).
- A-3 Nemerow, N. L., *"The Theories and Practice of Industrial Waste Treatment"*, Addison-Wesley Publishing Co., Inc., 76-83, (1963).
- A-4 Klassen, V. I. and Mokronsov, V. A., *"An Introduction to the Theory of Flotation"*, Butterworths, London, (1963).
- A-5 Mancy, K. H., and Okum, D. A., *"Effects of Surface Active Agents on Bubble Aeration"*, JWPCF, p. 361 (April 1960).
- A-6 Gaudin, A. M., *"Flotation"*, 1st Ed., McGraw-Hill Book Company, Inc., New York, p. 1047, (1932).
- A-7 Task A Report, FWQA Microscreening Study, pp. III-3, (July 1970).
- A-8 Wark, I. W. and Sutherland, K. L., *"Principles of Flotation"*, Australasian Institute of Mining and Metallurgy, pp. 365, (1955).
- A-9 Agrawal, G. D., Ph.D. Thesis, U. C. Berkeley.
- A-10 Brown, D. J., *"Fundamentals of Froth Flotation"*, Chemical and Process Engineering, (May 1966).
- A-11 Ettelt, G. A., *"Activated Sludge Thickening by Dissolved Air Flotation"*, Proc. 19th Purdue Ind. Waste Conf., p. 210 (1964).
- A-12 Fitch, E. B., *"Biological Treatment of Sewage and Industrial Wastes-Vol. 2: Anaerobic Digestion and Solids-Liquid Separation"*, McCabe, L., and Eckenfelder, W. W., Jr., (eds), Reinhold Publishing Corporation, New York, (1958).
- A-13 Eckenfelder, W. W., *"Industrial Water Pollution Control"*, McGraw-Hill, New York, (1966).
- A-14 Katz, W. J. and Geinopolos, A., *"Sludge Thickening by Dissolved-Air Flotation"*, FWPCF, Vol. 39, No. 6, 1 June 1967.
- A-15 Stumm, W., and Morgan, J. J., *"Chemical Aspects of Coagulation"*, Journal AWWA, Vol. 54 (8), p. 971, (1962).

APPENDIX A - LIST OF REFERENCES (Cont'd)

CITED REFERENCES (Cont'd)

- A-16 Ives, K. J., "*Filtration Through A Porous Septum-A Thoeretical Consideration of Boucher's Law*", Proceedings Inst. Civil Eng., Vol. 17 (6459), pp. 333-337, (November 1960).

LIST OF UNCITED REFERENCES

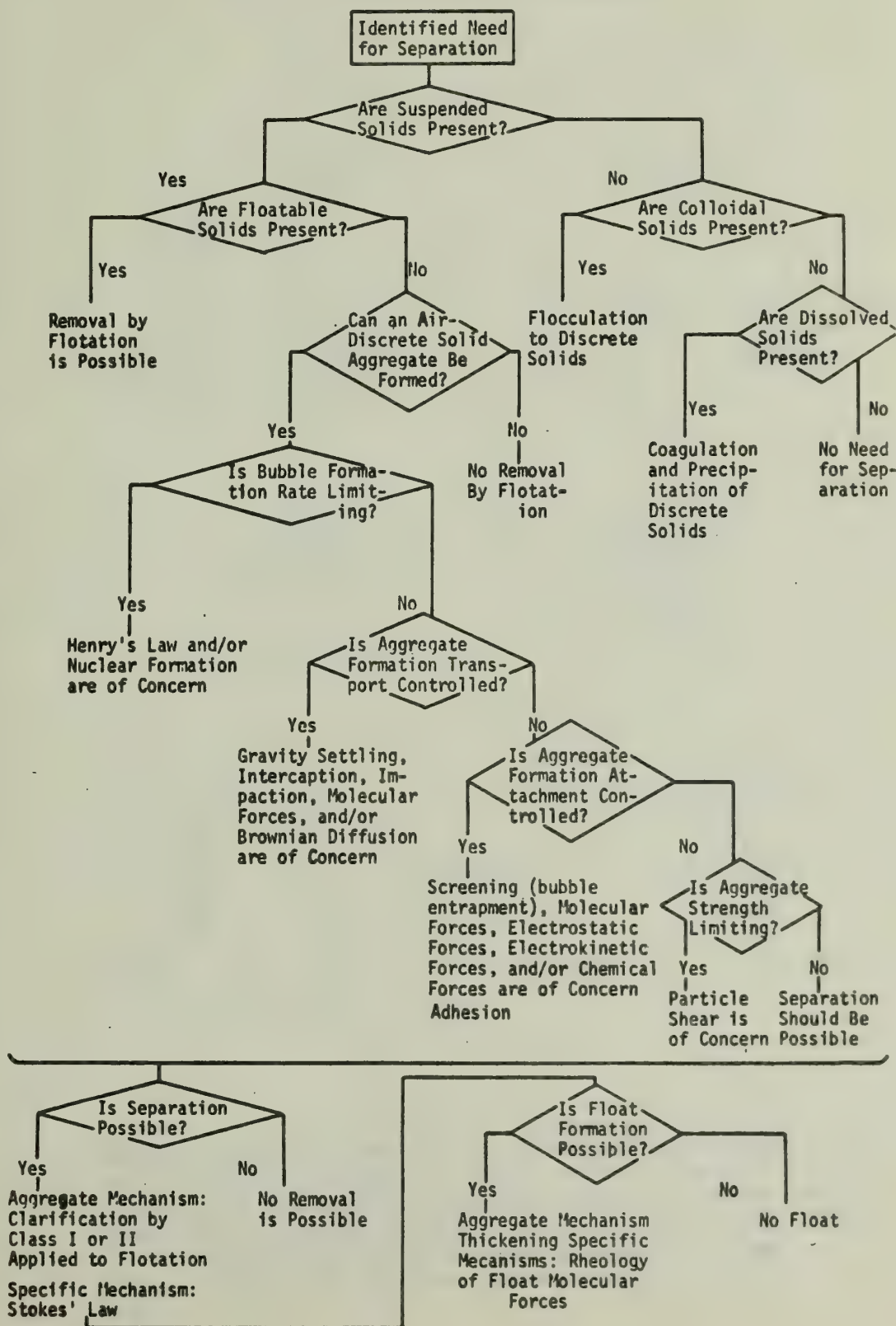
1. Kalinske, A. A., and Evans, R. R., "*Comparison of Flotation and Sedimentation in Treatment of Industrial Wastes*", Proceedings of the Seventh Industrial Waste Conference, Purdue University, Lafayette Ind., pp. 69-70, (1953).
2. Geinopolos, A., and Katz, W.J., "*Primary Treatment*", Chemical Engineering, 14 October 1968.
3. Vuuren, L. R. J., Stander, G. H., Henzen, M. R., Meiring, P. G. J., and Van Blerk, S. H. V., "*Advanced Purification of Sewage Work Effluent Using a Combined System of Lime Softening and Flotation*", Water Research, pp. 463-474, Pergamon Press Vol. 1 (1967).
4. Howe, Robert H. L., "*A Mathematical Interpretation of Flotation for Solids-Liquid Separation*", Biological Treatment of Sewage and Industrial Wastes - Vol. II Anaerobic Digestion and Solids-Liquid Separation, McCabe, J. and Eckenfelder, W. W. Jr., eds. Reinhold Publishing Corporation, New York pp. 241-250, 1958.
5. Rubin, A. J., and Lackey, S. C., "*Effect of Coagulation on the Micro-flotation of Bacillus Cereus*", Journal AWWA (October 1968).
6. Kasnova, G. S., Sheyler, L. D., and Mokrushin, "*Effect of Hydrogen Ion Concentration on Flotation of Colloids*".
7. Rubin, A. J., "*Removal of Trace Metals by Foam Separation Processes*", Journal AWWA, (July 1968).
8. Rich, L. G., "*Unit Operations of Sanitary Engineering*", John Wiley and Sons, Inc. New York-London, 110-118, (1961).
9. Mulbarger, M. C., and Huffman, D. D., "*Mixed Liquor Solids Separation by Flotation*", ASCE, San. Engr, Div., SA4, 7447, pp. 861, (August 1970).
10. Eckenfelder, W. W., Jr., Rooney, R. F., Barger, T. G., and Gruspeice, J. T., "*Studies on Dissolved Air Flotation of Biological Sludges*", Biological Treatment of Sewage and Ind. Waste - Vol. II, p. 251.

APPENDIX A - LIST OF REFERENCES (Cont'd)

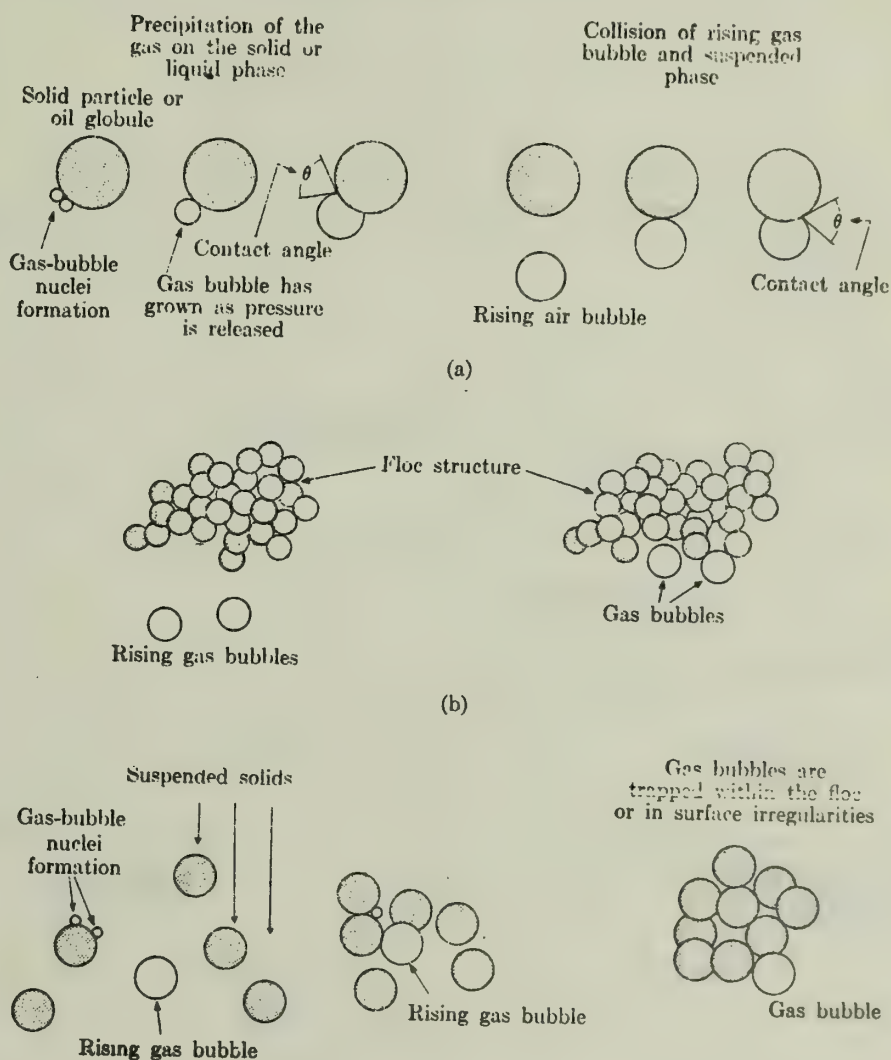
LIST OF UNCITED REFERENCES (Cont'd)

11. Geinopolos, A., and Katz, W. J. "*A Study of A Rotating Cylinder Sludge Collector in the Dissolved Air Flotation Process*", JWPCF, 36 (6), 712-721, (June 1964).

CONTEXT FOR VIEWING MECHANISMS IN FLOTATION

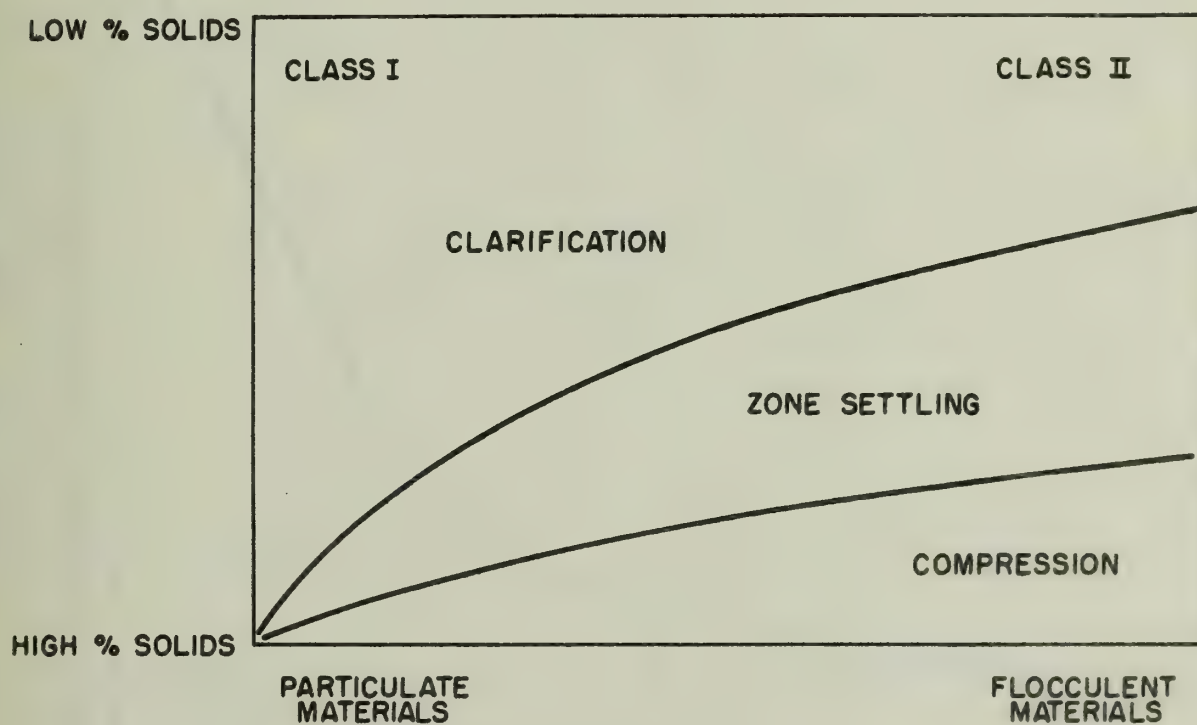


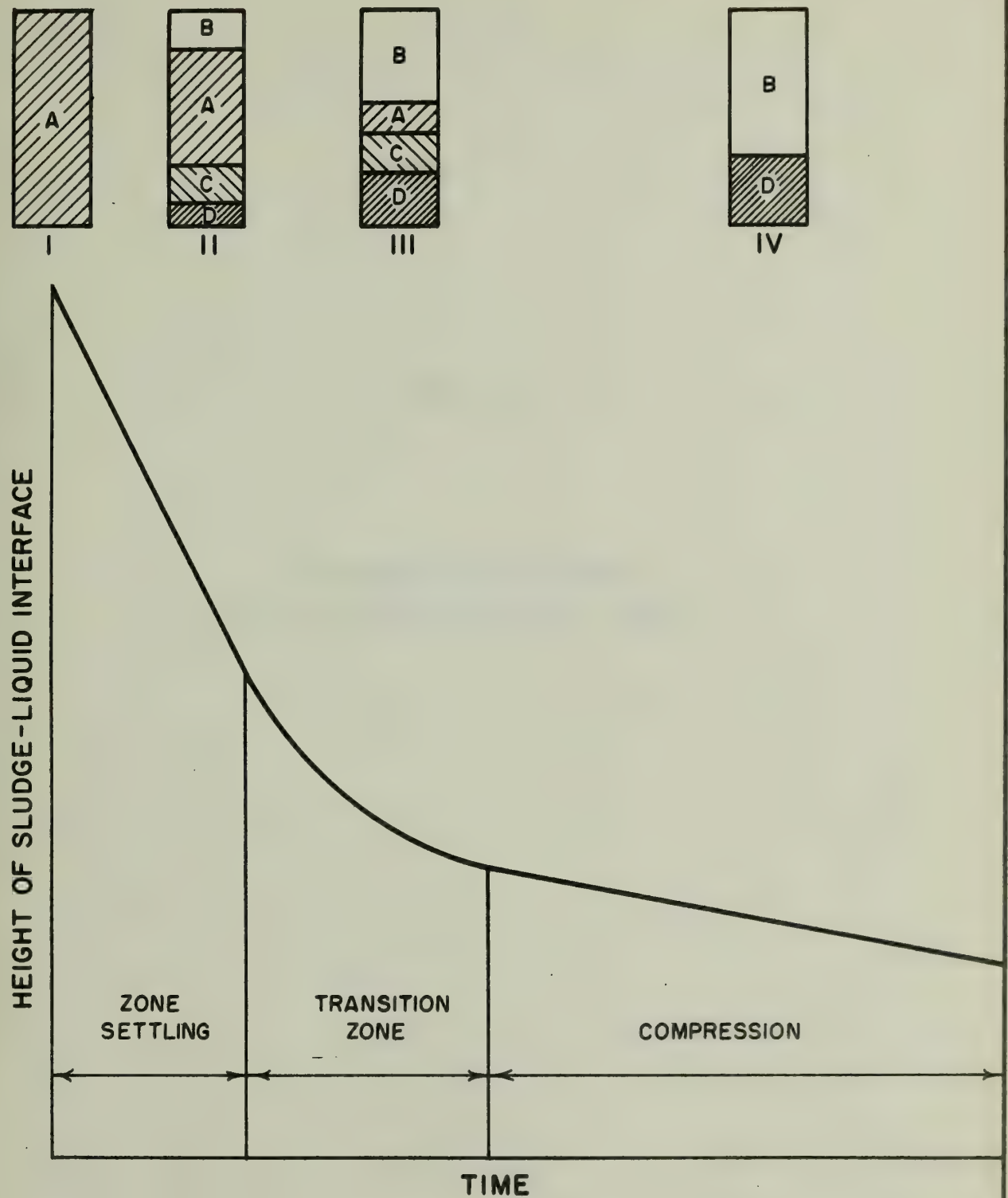
REMOVAL OF SUSPENDED SOLIDS



Three methods of dissolved-air flotation (a) Adhesion of a gas bubble to a suspended liquid or solid phase (b) the trapping of gas bubbles in a floc structure as the gas bubbles rise (c) the absorption and adsorption of gas bubbles in a floc structure as the floc structure is formed. [Figure from p.82, Nemerow, Reference A-4).

PARAGENESIS DIAGRAM
(From Reference A-12)





SETTLING PROPERTIES OF A FLOCCULATED SLUDGE (Reference V-9)

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APPENDIX B

INSTRUMENTATION AND CONTROLS
SECTION 26, SPECIFICATION NO. 23,060

APPENDIX B
INSTRUMENTATION AND CONTROLS
SECTION 26, SPECIFICATION NO. 23,060

26.01

General

The work to be done under this section includes the furnishing, installing, and testing of all items of equipment necessary to produce a complete and operable instrumentation and controls system as specified herein and as shown on the Contract Drawings.

26.02

Control Systems

Plant Prestart and Lead-Lag System

Prior to the onset of an overflow either the east or the west flotation system shall be set to operate first. This shall be accomplished by means of a two-way selector switch mounted on the control console. By placing the switch in the "east (west) position" the east (west) plant inlet gate will be set to open first and all the equipment for the east (west) flotation system will commence operation when actuated as described below. After a 0-60 minute adjustable time delay (time clock) after the east (west) magnetic flow meter is registering a preset flow value (the value set by the east (west) rate of flow controller), the west (east) gate will open and the west (east) flotation system will commence operation as described below. Shut-down of either the east, the west, or both flotation systems will be manual. All electrically operated equipment in both the east and west plant except motor operated skim pipes shall have hand-off-automatic switches. All hand-off-automatic switches except for bypass and plant inlet gates shall be console mounted, as shown on the Contract Drawings.

When an overflow does occur, the Low Level Probe at the intersection of Baker Street and Marina Boulevard shall send a signal to the

console mounted level relay. This relay shall actuate multiple contacts which shall direct power to the influent recorders, the ventilation system, and the hydraulic oil power unit. The Level Probe in the plant inlet structure shall send a signal to the console mounted level relay. This relay shall actuate one of two contacts (the contact chosen by the east-west selector switch) which shall signal one of the plant inlet gates to open. Flow shall increase to the preset control point as described below. When this point is reached the time clock shall be actuated by the Flow Recorder. After the 0-60 adjustable time delay has elapsed, the time contacts shall close and the other plant inlet gate shall be directed to open.

Screenings Removal Equipment System

As soon as the east (west) magnetic influent flow meter senses flow, both the east (west) mechanically cleaned bar screen and screenings conveyor will commence operation. When the east (west) system has reached its preset flow value, the west (east) system is placed in operation and the sensing of flow by the west (east) magnetic flow meter will cause the west (east) bar screen to commence operation. This equipment shall have HOA switches.

Influent Flow Metering, Control, Indicating, and Recording System

The influent to each flotation system shall pass through a 30-inch diameter butterfly valve with electronic operator and thence through a 30-inch diameter magnetic flow meter. The magnetic flow meter shall be powered by an exterior 120 v, 60 cycle current. An electronic signal converter shall be mounted on the magnetic flow meter. The signal converter shall take a 60 cycle ac signal and convert it to 4-20 ma dc signal, and it shall send this signal to each of four (4) panel-mounted instruments as follows: (1) flow recorder, (2) current converter, (3) flow controller, and (4) flow adder. The signal converter shall also send a pulse signal to a panel-mounted flow integrator which will add up to the total volume for any given treatment cycle. The flow recorder will record and indicate the flow.

The current converters will amplify the 4-20 ma dc signal for use in the Chemical Feeding Systems. The flow adder will sum the flows from both flotation systems and this total flow signal will be used in the Bypass Control Gates System. The flow controller shall be manually set and shall compare one (1) particular set point with the incoming signal and in turn shall send a signal to the electric operator on the butterfly valve to make any necessary corrections in valve position required to maintain a manually set rate-of-flow versus the actual rate of flow.

Flotation Tank Equipment System

The Flotation Tank Equipment for each system (consisting of sludge collectors, screw conveyors, recycle pumps, air compressors, air lift valves and skim pipes) shall be activated by the combination of two (2) conditions: (1) the sensing by the level transmitter in the flotation tank of a prescribed level and (2) the sensing by the magnetic influent flow meter of a prescribed minimum flow. The level transmitter shall send a 4-20 ma dc signal, linear with the differential pressure, to a panel-mounted level indicator. The signal shall be sent by the level indicator to the motor control center by means of the equipment control circuitry. The conditions which control the start-up of the equipment also determine its shut-down. All equipment will have HOA switches.

Chemical Feeding Systems

The console-mounted Current-to-Current Converter (I/I) shall send a 4-20 ma dc signal, linear with flow to two (2) chemical feeding systems.

Sodium Hypochlorination System: The linear output from the I/I shall be used by the automatic electric input controller mounted on each sodium hypochlorite feed pump. (Controller and pump by other; see Section 25 of the Specifications).

Coagulant Feeding System: The linear output from the I/I shall be used by the automatic electric input controllers mounted on the two (2) polyelectrolyte pumps, the alum pump, and the caustic pump. By means of a console-mounted two-position switch, polyelectrolyte can be fed

to each flotator, or polyelectrolyte can be fed to either flotator and alum and caustic can be fed to the other one.

Bypass Control Gates System

The console-mounted Flow Adder (described in an above section) shall send a 4-20 ma dc signal to the console-mounted dual alarm relay type Electronic Trip. When the signal to the trip exceeds the preset level, this same signal shall be sent to console-mounted gate Flow Controller. This Flow Controller shall send a 4-20 ma dc signal to the console-mounted Control Valve Positioners. These Positioners shall be used to position the gates by comparing gate position from a 4-20 ma dc output signal from the gate opening feedback indicator-transmitter which shall sense mechanical gate motion. Operating relays in the positioner shall direct operation of the hydraulic oil system solenoid operated, directional control valves, furnished under Section 36 of these Special Provisions. (The gates and operating systems shall be by others as described in Sections 25 and 36 of these Special Provisions). When the total plant flow, as measured by the Flow Adder, equals or exceeds the preset point on the gate Flow Controller, the gates will open in parallel to bypass excess flow. When the total plant flow is less than the present point, the gates will: (1) move toward the closed position; or (2) remain closed, if already closed.

When the influent flow exceeds the hydraulic constraints of the facility, the Bypass Gates will be actuated by an emergency actuating system. Emergency High Level and Emergency Low Level Cut-Out Probes shall sense the water levels in the overflow structure located at the intersection of Marina Boulevard and Baker Street, as shown in the Contract Drawings. When the water level reaches a preset and adjustable level, a signal is sent to a console-mounted Level Relay. This Level Relay shall connect a control relay into the gate control circuit. This relay shall cause each gate to open, as described in Section 25 of the Special Provisions. When the water level in the overflow structure at Baker and Marina falls below the emergency cut-out level, a signal is sent to the console-mounted Level Relay which shall again allow the gate flow control signal to operate the bypass gates.

Solids Handling System

The solids handling pump shall be controlled by an electronic differential pressure sensing device mounted in the solids sump, as shown on the Contract Drawings. The differential pressure sensing device shall receive its power from a dc power supply with an output of 45 volts dc. As the level in the solids sump fluctuates, the electronic differential pressure sensor shall send a 4-20 ma dc linear output signal to the variable speed control panel mounted in the motor control center. (Variable speed control panel by others. See Section 27 of the Specifications.) The variable speed control panel shall control the speed of the solids handling pump according to the conditions of Section 25 of the Specifications.

The flow through the pump shall be metered by means of a magnetic flow meter on the discharge side of the pump. An electronic signal shall be sent from the magnetic flow meter to a locally mounted flow indicator and integrator. Both the flow indicator and the flow integrator shall be field mounted in one common panel, as shown on the Contract Drawings.

The solids handling system shall operate independently of the flotation units.

APPENDIX C

LABORATORY DATA

TABLE C-1

RESULTS OF JAR TEST # 1
(ALUM AND CAUSTIC)

Characteristics	Beaker Number				
	B1	B2	B3	B4	B5
Dosage (mg/l)					
Alum	80.0	80.0	80.0	80.0	80.0
Purifloc C-31	-	-	-	-	-
Caustic Soda	20.0	15.0	10.0	5.0	0.0
Effluent pH	7.2	7.2	7.2	7.2	7.2
Effl. Solids, mg/l	90.0	110.0	100.0	120.0	125.0
% TSS Removal	36.6	22.5	39.6	16.0	12.0
Specific Chem. Dose					
Alum, mg/mg	-	-	-	-	-
C-31, mg/mg	-	-	-	-	-
NaOH, mg/mg	-	-	-	-	-
					Blank
					-
					0.0
					7.2
					92.0
					35.0

NOTES: (1) Date: 9 September 1970.

(2) Initial TSS (mg/l) = 140.

(3) Initial alkalinity = 200 mg/l as CaCO_3

(4) Temperature $^{\circ}\text{C}$ = 16.5

(5) pH = 7.2

TABLE C-2

RESULTS OF JAR TEST # 2
(ALUM AND CAUSTIC)

Characteristics	Beaker Number					
	B1	B2	B3	B4	B5	B6
Dosage (mg/l)						
Alum	240.00	240.00	240.00	240.00	240.00	Blank
Purifloc C-31	-	-	-	-	-	-
Caustic Soda	60.00	45.00	30.00	15.00	0.00	-
Effluent pH	7.00	-	-	-	-	7.2
Effl. Solids, mg/l	65.00	50.00	42.00	56.00	52.00	98.0
% TSS Removal	46.00	64.00	70.00	60.00	63.00	30.0
Specific Chem. Dose						
Alum, mg/mg	1.70	1.70	1.70	1.70	1.70	0.0
C-31, mg/mg	-	-	-	-	-	-
NaOH, mg/mg	0.43	0.32	0.21	0.11	0.00	-
meq Caustic/meq Alum	0.69	0.52	0.35	0.17	0.00	0.0

NOTES: (1) Date: 29 September 1970.

(2) Initial TSS (mg/l) = 140

(3) Initial alkalinity = 200 mg/l as CaCO₃

(4) Temperature °C = 16.5

(5) pH = 7.2

TABLE C-3

RESULTS OF JAR TEST # 3
(ALUM ONLY)

Characteristics	Beaker Number					
	B1	B2	B3	B4	B5	B6
Dosage (mg/l)						
Alum	350.0	300.00	250.0	200.00	150.00	100.0
Purifloc C-31	-	-	-	-	-	-
Caustic Soda	-	-	-	-	-	--
Effluent pH	5.9	6.10	6.2	6.40	6.50	6.7
Effl. Solids, mg/l	14.0	15.00	46.0	110.00	125.00	130.0
% TSS Removal	90.0	89.00	67.0	21.00	11.00	7.0
Specific Chem. Dose						
Alum, mg/mg	2.5	2.14	1.8	1.43	1.07	0.7
C-31, mg/mg	-	-	-	-	-	-
NaOH, mg/mg	-	-	-	-	-	-

NOTES: (1) Refrigerated sample.

(2) Sample tested for alkalinity (200 mg/l as CaCO_3) before Test No. 3 was conducted.

(3) Date: 30 September 1970

(4) Initial TSS (mg/l) = 140

(5) Temperature $^{\circ}\text{C}$ = 16.0

(6) Initial pH = 7.4

TABLE C-4

RESULTS OF JAR TEST # 4.
(PURIFLOC C-31 ONLY)

Characteristics	Beaker Number					
	B1	B2	B3	B4	B5	B6
Dosage (mg/l)						
Alum	-	-	-	-	-	-
Purifloc C-31	224.0	168.0	110.0	44.8	22.4	11.2
Caustic Soda	-	-	-	-	-	-
Effluent pH			No Measurement			
Effl. Solids, mg/l	-	-	-	-	-	-
% TSS Removal	-	-	-	-	-	-
Specific Chem. Dose						
Alum, mg/mg	-	-	-	-	-	-
C-31, mg/mg	-	-	-	-	-	-
NaOH, mg/mg	-	-	-	-	-	-

NOTES: (1) All Effluents were very turbid.

(2) Date: 30 September 1970

(3) Initial TSS (mg/l) = 140

(4) Temperature °C = 19

(5) pH = 7.4

TABLE C-5

RESULTS OF JAR TEST # 5
(PURIFLOC C-31 ONLY)

Characteristics	Beaker Number					
	B1	B2	B3	B4	B5	B6
Dosage (mg/l)						
Alum	-	-	-	-	-	-
Purifloc C-31	22.40	16.50	11.20	4.400	2.200	1.100
Caustic Soda	-	-	-	-	-	-
Effluent pH	7.10	7.10	7.10	7.100	7.100	7.100
Effl. Solids, mg/l	130.00	125.00	122.00	91.000	87.000	85.000
% TSS Removal	7.00	11.00	13.00	34.000	38.000	39.000
Specific Chem. Dose						
Alum, mg/mg	-	-	-	-	-	-
C-31, mg/mg	0.16	0.12	0.08	0.031	0.015	0.008
NaOH, mg/mg	-	-	-	-	-	-

NOTES: (1) New Sample batch used for tests.

(2) Date: 1 October 1970

(3) Initial TSS (mg/l) = 140

(4) Temperature, °C = 16

(5) pH = 7.1

TABLE C-6

RESULTS OF JAR TEST # 6
(PURIFLOC A-23 ONLY)

Characteristics	Beaker Number					
	B1	B2	B3	B4	B5	B6
Dosage (mg/l)						
Alum	-	-	-	-	-	-
Purifloc A-23	1.0	0.5	0.1	0.08	0.05	0.03
Caustic Soda	-	-	-	-	-	-
Effluent pH	7.1	7.1	7.1	7.10	7.10	7.10
Effl. Solids, mg/l	125.0	122.0	122.0	122.00	118.00	120.00
% TSS Removal	11.0	13.0	13.0	13.00	16.00	16.00
Specific Chem. Dose						
Alum, mg/mg	-	-	-	-	-	-
A-23, mg/mg	0.007	0.004	0.0007	0.00056	0.0004	0.0002
NaOH, mg/mg	-	-	-	-	-	-

NOTES: (1) Date: 1 October 1970

(2) Initial TSS (mg/l) = 140

(3) Temperature, °C = 23

(4) pH = 7.0

TABLE C-7

RESULTS OF JAR TEST # 7
(ALUM AND PRUIFLOC C-31)

Characteristics	Beaker Number					
	B1	B2	B3	B4	B5	B6
Dosage (mg/l)						
Alum	250.0	250.0	250.0	150.0	150.0	150.0
Purifloc C-31	0.6	1.1	2.2	0.6	1.1	2.2
Caustic Soda	-	-	-	-	-	-
Effluent pH	6.2	6.3	6.2	6.5	6.6	6.6
Effl. Solids, mg/l	30.0	25.0	12.0	200.0	170.0	180.0
% TSS Removal	78.0	82.0	91.0	0.0	0.0	0.0
Specific Chem. Dose						
Alum, mg/mg	1.8	1.8	1.8	1.07	1.07	1.07
C-31, mg/mg	0.004	0.008	0.015	-	-	-
NaOH, mg/mg	-	-	-	-	-	-

NOTES: (1) Date: 1 October 1970

(2) Initial TSS (mg/l) = 140

(3) Temperature, °C = 23

(4) pH = 7.0

TABLE C-8

RESULTS OF JAR TEST # 8
(ALUM AND PURIFLOC C-31)

Characteristics	Beaker Number					
	B1	B2	B3	B4	B5	B6
Dosage (mg/l)						
Alum	250.00	250.00	250.00	250.00	250.00	Blank
Purifloc C-31	5.50	4.40	2.75	1.65	1.10	Blank
Caustic Soda	-	-	-	-	-	-
Effluent pH	6.10	6.10	6.10	6.10	6.10	7.2
Effl. Solids, mg/l	38.00	27.00	40.00	56.00	57.00	160.0
% TSS Removal	81.00	87.00	80.00	72.00	72.00	20.0
Specific Chem. Dose						
Alum, mg/mg	1.25	1.25	1.25	1.25	1.25	0.0
C-31, mg/mg	0.028	0.022	0.014	0.008	0.006	0.0
NaOH, mg/mg						

NOTES: (1) Date: 2 October 1970

(2) Initial TSS (mg/l) = 200

(3) Temperature, °C = 22

(4) pH = 7.2

TABLE C-9

SUMMARY OF RESULTS
LABORATORY FLOTATION CELL EXPERIMENTS

Characteristics	Run				
	1	2	3	4	5
1. Vol, Sample, l/Pressurized, l	20/4	20/4	20/4	20/4	20/4
2. Pressure, psig	65.0	65.000	65.000	65.000	65.000
3. Initial Solids, mg/l	158.0	158.000	158.000	158.000	132.000
4. Effluent Solids @ 30 min, mg/l	100.0	59.000	114.000	122.000	48.000
5. % TSS removed	37.0	62.600	27.900	22.800	63.600
6. TSS in float @ 30 min, mg/l	-	1,610.000	2,280.000	2,360.000	2,680.000
7. Float thickness, inches	-	-	1.500	1.500	1.500
8. Float Vol. (litres)*	-	-	0.312	0.312	0.312
9. Float Solids Production (lbs/ft ² /day)	-	-	0.850	0.880	1.010
10. Infl. Floatables, mg/l	-	1.500	1.500	1.500	1.500
11. Effl. Floatables, mg/l	-	0.500	0.700	0.200	0.400
12. % Floatables Removed	-	66.600	53.400	86.600	95.500
13. Infl. Temperature, °C	21.0	16.500	16.500	16.000	16.500
14. Alum (mg/mg TSS)	0.0	1.800	1.600	1.800	2.150
15. C-31 (mg/mg TSS)	0.0	0.018	0.018	0.020	0.029
16. Infl. pH	7.2	7.200	7.200	7.200	7.300
17. Effl. pH @ 30 min	7.2	6.500	8.500	7.100	7.000

TABLE C-9 (Cont'd)

Characteristics	Run					
	6	7	8	9	10	11
1. Vol, Sample, l/Pressurized, l	20/4	20/4	20/4	20/4	20/4	20/4
2. Pressure, psig	65.000	65.000	65.000	65.000	65.000	65.000
3. Initial Solids, mg/l	132.000	132.000	132.000	160.000	160.000	160.000
4. Effluent Solids @ 30 min, mg/l	36.000	58.000	44.000	70.000	52.000	58.000
5. % TSS removed	72.600	56.000	66.600	43.800	67.400	63.800
6. TSS in float @ 30 min, mg/l	3,670.000	2,430.000	4,090.000	1,220.000	4,520.000	2,490.000
7. Float thickness, inches	1.600	1.900	1.900	1.500	1.700	2.000
8. Float Vol. (litres)*	0.333	0.396	0.396	0.312	0.354	0.416
9. Float Solids Production (lbs/ft ² /day)	1.460	1.160	1.940	0.450	1.910	1.200
10. Infl. Floatables, mg/l	8.700	8.700	8.700	4.600	4.600	4.600
11. Effl. Floatables, mg/l	0.200	0.200	0.350	0.200	0.600	0.200
12. % Floatables Removed	97.600	97.600	96.000	95.700	87.000	95.700
13. Infl. Temperature, °C	16.800	17.000	17.000	17.000	16.000	16.000
14. Alum (mg/mg TSS)	2.150	2.150	1.800	1.800	1.800	1.800
15. C-31 (mg/mg TSS)	0.036	0.015	0.018	0.015	0.029	0.036
16. Infl. pH	7.300	7.300	7.400	7.600	6.700	6.900
17. Effl. pH @ 30 min	7.000	7.000	6.800	6.500	6.300	6.300

NOTES: (1) Surface area = 0.088 ft².

* 1 ft of flotation cell = 2.5 litres.

TABLE C-10

SUMMARY OF RESULTS
LABORATORY FLOTATION CELL TEST
(POLYMER C-31 ONLY)

Characteristics	12	13	14	15	16
1. Vol, Sample, l/Pressurized, l	20/4	20/4	20/4	20/4	20/4
2. Pressure, psig	65.000	65.000	65.000	65.000	65.000
3. Initial Solids, mg/l	212.000	146.000	146.000	146.000	146.000
4. Effluent Solids @ 30 min, mg/l	74.000	66.000	50.000	54.000	34.000
5. % TSS removed	70.000	55.000	66.000	63.000	77.000
6. TSS in float @ 30 min, mg/l	755.000	313.000	-	-	-
7. Float thickness, inches	0.380	0.500	(-)	(-)	(-)
8. Float Vol. (litres)*	0.079	0.104	-	-	-
9. Float Solids Production (lbs/ft ² /day)	0.070	0.040	-	-	-
10. Infl. Floatables, mg/l	18.200	5.300	5.300	5.300	5.300
11. Effl. Floatables, mg/l	0.200	0.300	0.200	0.200	0.200
12. % Floatables Removed	99.000	94.000	96.000	96.000	96.000
13. Infl. Temperature, °C	16.500	18.000	16.500	17.000	17.500
14. Alum (mg/mg TSS)	-	-	-	-	-
15. C-31 (mg/mg TSS)	0.010	0.025	0.060	1.020	0.035
16. Infl. pH	7.400	7.300	7.400	7.200	7.200
17. Effl. pH @ 30 min	7.400	7.300	7.300	7.100	7.200

NOTES: (1) (-) Not Measurable.

TABLE C-11

LABORATORY FLOTATION CELL INLET
REYNOLDS NUMBER CALCULATION

Run Number	Run							
	1	2	3	4	5	6	7	8
1. Sample Transfer Time (min)	1.05	1.20	1.00	1.18	1.62	0.83	0.93	1.35
2. Gross Hydraulic Loading Rate (gpm)**	1.00	0.88	1.06	0.90	0.65	1.28	1.14	0.78
3. Average Inlet Velocity, ft/sec	0.72	0.63	0.76	0.65	0.47	0.92	0.82	0.56
4. Average Inlet Reynolds Number (VD/η)*	3,700.00	3,240.00	3,900.00	3,350.00	2,420.00	4,740.00	4,220.00	3,880.00

TABLE C-11 (Cont'd)

Run Number	Run							
	9	10	11	12	13	14	15	16
1. Sample Transfer Time (min)	0.72	1.50	1.38	0.93	1.15	1.03	0.75	1.15
2. Gross Hydraulic Loading Rate, (gpm)***	1.47	0.71	0.77	1.14	0.92	1.03	1.41	0.92
3. Average Inlet Velocity, ft/sec	1.06	0.51	0.55	0.82	0.66	0.74	1.01	0.66
4. Average Inlet Reynolds Number (VD/ η)	5,460.00	2,630.00	2,830.00	4,220.00	3,400.00	3,800.00	5,200.00	3,400.00

NOTES: (1) Kinematic viscosity of water at 17°C (1.217×10^{-5}) assumed for all waste samples.

* Inlet pipe diameter = 3/4 in = 0.0625 ft, Area $\cong 0.0031$ ft².

** $\text{gpm} = (4 \text{ gal}/3.785 \text{ l}) \frac{1}{\theta \text{ min.}} = (1.06/\theta)$.

TABLE C-12
LABORATORY FLOTATION CELL BASIC DATA
(RUN 1)

Height (ft)	Item	R1	R2	R3	R4	R5	R6	R7
1	Time (min)	0.5	1.5	7	12	-	-	-
	JTU	52	48	45	37	-	-	-
	TSS (mg/l)							
	% Removal							
2	Time (min)	-	-	-	-	-	-	-
	JTU	-	-	-	-	-	-	-
	TSS (mg/l)	-	-	-	-	-	-	-
	% Removal	-	-	-	-	-	-	-
3	Time (min)	1	4	8	16			
	JTU	48	45	No Sample	42	-	-	-
	TSS (mg/l)							
	% Removal							
4	Time (min)	-	-	-	-	-	-	-
	JTU	-	-	-	-	-	-	-
	TSS (mg/l)	-	-	-	-	-	-	-
	% Removal	-	-	-	-	-	-	-
5	Time (min)	2	5	10	20	-	-	-
	JTU	45	42	41	38			
	TSS (mg/l)							
	% Removal							
6	Time (min)	-	-	-	-	-	-	-
	JTU	-	-	-	-	-	-	-
	TSS (mg/l)	-	-	-	-	-	-	-
	% Removal	-	-	-	-	-	-	-
7	Time (min)	3	6	15	30			
	JTU	45	41	44	-			
	TSS (mg/l)							
	% Removal							

Average final turbidity = 40 JTU.

Average final TSS = 100 mg/l.

Percent TSS removal = 37.

TABLE C-13
LABORATORY FLOTATION CELL BASIC DATA
(RUN 2)

Height (ft)	Item	R1	R2	R3	R4	R5	R6	R7
1	Time (min)	0.5	1.5	7	12	30		
	JTU	115	108	47	37	44		
	TSS (mg/l)	230	220	115	93	110		
	% Removal	-	-	27.3	41.2	30.4		
2	Time (min)	-	-	-	-	-	-	-
	JTU							
	TSS (mg/l)							
	% Removal							
3	Time (min)	1	4	8	16			
	JTU	135	120	34	37			
	TSS (mg/l)	261	240	90	93			
	% Removal	-	-	43.1	41.2			
4	Time (min)	-	-	-	-	-	-	-
	JTU	-	-	-	-	-	-	-
	TSS (mg/l)							
	% Removal							
5	Time (min)	2	5	10	20	30		
	JTU	148	121	39	34	30		
	TSS (mg/l)	280	240	100	90	80		
	% Removal	-	-	36.7	43.1	49.4		
6	Time (min)	-	-	-	-	-	-	-
	JTU	-	-	-	-	-	-	-
	TSS (mg/l)	-	-	-	-	-	-	-
	% Removal	-	-	-	-	-	-	-
7	Time (min)	2.5	6	15	30	-	-	-
	JTU	130	127	45	30			
	TSS (mg/l)	225	250	111	80			
	% Removal							

TABLE C-14
LABORATORY FLOTATION CELL BASIC DATA
(RUN 3)

Height (ft)	Item	R1	R2	R3	R4	R5	R6	R7
1	Time (min)	0.5	1.5	7	12	30	-	-
	JTU	128	52	37	36	43	-	-
	TSS (mg/l)	250	123	95	93	108	-	-
	% Removal	-	22.2	39.9	41.2	31.6	-	-
2	Time (min)	-	-	-	-	-	-	-
	JTU	-	-	-	-	-	-	-
	TSS (mg/l)	-	-	-	-	-	-	-
	% Removal	-	-	-	-	-	-	-
3	Time (min)	1	4	8	16	-	-	-
	JTU	137	65	42	39	-	-	-
	TSS (mg/l)	262	149	105	100	-	-	-
	% Removal	-	5.7	33.6	36.8	-	-	-
4	Time (min)	-	-	-	-	-	-	-
	JTU	-	-	-	-	-	-	-
	TSS (mg/l)	-	-	-	-	-	-	-
	% Removal	-	-	-	-	-	-	-
5	Time (min)	2	5	10	20	30	-	-
	JTU	137	132	43	39	40	-	-
	TSS (mg/l)	262	260	107	100	101	-	-
	% Removal	-	-	32.3	36.8	35.5	-	-
6	Time (min)	-	-	-	-	-	-	-
	JTU	-	-	-	-	-	-	-
	TSS (mg/l)	-	-	-	-	-	-	-
	% Removal	-	-	-	-	-	-	-
7	Time (min)	3	6	15	30	-	-	-
	JTU	134	134	42	40	-	-	-
	TSS (mg/l)	261	261	106	101	-	-	-
	% Removal	-	-	33	35.5	-	-	-

TABLE C-15
LABORATORY FLOTATION CELL BASIC DATA
(RUN 4)

Height (ft)	Item	R1	R2	R3	R4	R5	R6	R7
1	Time (min)	1:00	6:00	10:00	12:30	22:00	33:15	-
	JTU	30	28	25	25	26	28	-
	TSS (mg/l)	80	76	70	70	72	76	-
	% Removal	49.4	52	55.6	55.6	54.5	52	-
2	Time (min)	1:30	6:15	10:15	12:45	22:15	33:00	-
	JTU	35	28	28	31	31	32	-
	TSS (mg/l)	92	76	76	82	82	85	-
	% Removal	41.8	52	52	48.2	48.2	46.3	-
3	Time (min)	5:00	6:30	10:30	13:00	22:30	32:45	-
	JTU	45	33	35	35	34	32	-
	TSS (mg/l)	111	87	92	92	90	85	-
	% Removal	39.8	45	41.8	41.8	43	46.3	-
4	Time (min)	2:00	7:00	10:45	13:15	22:45	32:30	-
	JTU	90	46	35	35	35	33	-
	TSS (mg/l)	180	112	92	92	92	87	-
	% Removal	-	29.1	41.8	41.8	41.8	45	-
5	Time (min)	3:00	7:30	11:00	15:30	23:00	32:15	-
	JTU	75	45	39	48	37	33	-
	TSS (mg/l)	167	111	99	118	93	87	-
	% Removal	-	29.8	37.4	25.4	41.2	45	-
6	Time (min)	3:45	8:30	11:15	16:00	24:00	32:00	-
	JTU	75	55	44	39	35	33	-
	TSS (mg/l)	167	130	110	99	92	87	-
	% Removal	-	17.7	30.4	37.4	41.8	45	-
7	Time (min)	3:30	9:00	11:30	16:45	24:15	-	-
	JTU	75	69	50	44	38	-	-
	TSS (mg/l)	167	152	120	110	97	-	-
	% Removal	-	3.8	24.1	30.4	38.8	-	-

TABLE C-16
LABORATORY FLOTATION CELL BASIC DATA
(RUN 5)

Height (ft)	Item	R1	R2	R3	R4	R5	R6	R7
1	Time (min)	1:00	3:00	6:00	8:30	11:00	15:00	18:00
	JTU	23	12	9.4	9.2	9.5	9.5	9.6
	TSS (mg/l)	77	48	41	40	42	42	42
	% Removal	41.6	63.6	69	69.9	68.3	68.3	68.3
2	Time (min)	1:15	3:15	6:15	8:45	11:45	15:09	18:30
	JTU	40	14	14	14	14	13	18
	TSS (mg/l)	116	54	54	54	54	52	65
	% Removal	12.1	59.1	59.1	59.1	59.1	60.6	50.7
3	Time (min)	1:30	3:30	6:30	9:00	11:30	15:19	19:30
	JTU	70	24	18	18	18	20	20
	TSS (mg/l)	170	80	65	65	65	70	70
	% Removal	-	39.4	50.7	50.7	50.7	47	47
4	Time (min)	1:45	3:45	6:45	9:15	11:45	15:30	20:00
	JTU	170	20	20	22	24	22	22
	TSS (mg/l)	320	70	70	75	80	75	75
	% Removal	-	47	47	43.2	39.4	43.2	43.2
5	Time (min)	2:00	4:00	7:00	9:30	12:00	15:46	20:30
	JTU	65	28	25	24	22	24	18
	TSS (mg/l)	161	90	82	80	75	80	65
	% Removal	-	31.8	38	39.4	43.2	39.4	50.7
6	Time (min)	2:15	4:15	7:15	9:45	12:15	16:15	21:00
	JTU	59	33	27	24	28	18	18
	TSS (mg/l)	151	100	87	80	90	65	65
	% Removal	-	24.3	34	39.4	31.8	50.7	50.7
7	Time (min)	2:30	4:30	7:30	10:00	12:30	-	-
	JTU	60	38	29	27	23	-	-
	TSS (mg/l)	152	110	91	87	77	-	-
	% Removal	-	16.7	31	34	41.6	-	-

TABLE C-17
LABORATORY FLOTATION CELL BASIC DATA
(RUN 6)

Height (ft)	Item	R1	R2	R3	R4	R5	R6	R7
1	Time (min)	1:00	3:00	4:30	6:00	10:06	15:00	29:30
	JTU	43	20	17	20	17	20	20
	TSS (mg/l)	121	70	63	70	63	70	70
	% Removal	8.35	47	52.3	47	52.3	47	47
2	Time (min)	1:15	3:09	4:37	6:09	10:00	15:07	29:41
	JTU	55	23	18	21	17	18	16
	TSS (mg/l)	145	77	65	73	63	65	60
	% Removal	-	41.6	50.8	44.7	52.3	50.8	54.6
3	Time (min)	1:30	3:15	4:43	6:13	9:50	15:13	29:47
	JTU	60	17	22	15	18	18	16
	TSS (mg/l)	152	63	75	58	65	65	60
	% Removal	-	52.3	43.2	56	50.8	50.8	54.6
4	Time (min)	1:45	3:23	4:49	6:19	9:40	15:19	29:53
	JTU	79	17	21	20	20	16	17
	TSS (mg/l)	188	63	73	70	70	60	63
	% Removal	-	52.3	44.6	47	47	54.6	52:3
5	Time (min)	2:10	3:30	5:00	6:27	9:30	15:27	30:00
	JTU	130	30	24	22	20	17	16
	TSS (mg/l)	270	94	80	75	70	63	60
	% Removal	-	28.8	29.4	43.2	47	52.3	54:6
6	Time (min)	2:15	3:45	5:14	6:45	9:15	15:40	30:16
	JTU	175	50	30	27	23	18	17
	TSS (mg/l)	330	132	94	87	77	65	63
	% Removal	-	-	28.8	34	41.6	50.8	52:3
7	Time (min)	2:30	4:08	5:25	7:00	9:00	-	-
	JTU	250	110	35	25	24	-	-
	TSS (mg/l)	440	240	105	82	80	-	-
	% Removal	-	-	20.5	38	39.4	-	-

TABLE C-18
LABORATORY FLOTATION CELL BASIC DATA
(RUN 7)

Height (ft)	Item	R1	R2	R3	R4	R5	R6	R7
1	Time (min)	1:00	2:30	5:00	8:00	14:13	19:30	29:30
	JTU	44	21	15	17	18	20	16
	TSS (mg/l)	123	73	58	63	65	70	60
	% Removal	6.8	44.8	56	52.3	50.8	47	54.6
2	Time (min)	1:08	2:37	5:07	8:07	14:19	19:37	29:41
	JTU	29	15	13	13	13	14	15
	TSS (mg/l)	91	58	52	52	52	54	58
	% Removal	31	56	60.6	60.6	60.6	59	56
3	Time (min)	1:15	2:50	5:13	8:11	14:23	19:42	29:47
	JTU	23	15	19	13	13	13	12
	TSS (mg/l)	77	58	67	52	52	52	48
	% Removal	41.6	56	-	60.6	60.6	60.6	63.5
4	Time (min)	1:23	2:51	5:19	8:16	14:30	19:49	29:53
	JTU	23	13	12	12	13	13	13
	TSS (mg/l)	77	52	48	48	52	52	52
	% Removal	41.6	60.6	63.5	63.5	60.6	60.6	60.6
5	Time (min)	1:30	3:11	5:25	8:23	14:39	19:57	30:00
	JTU	29	14	12	12	12	11	10
	TSS (mg/l)	91	54	48	48	48	46	43
	% Removal	31	59	63.5	63.5	63.5	65	67.4
6	Time (min)	1:45	3:23	5:37	8:37	14:50	20:15	30:15
	JTU	17	16	12	12	12	10	10
	TSS (mg/l)	63	60	48	48	48	43	43
	% Removal	52.3	54.6	63.5	63.5	63.5	67.4	67.4
7	Time (min)	2:00	3:30	5:45	8:44	15:00	20:30	-
	JTU	120	17	13	12	11	-	-
	TSS (mg/l)	250	63	52	48	46	-	-
	% Removal	-	52.3	60.6	63.5	65	-	-

TABLE C-19
LABORATORY FLOTATION CELL BASIC DATA
(RUN 8)

Height (ft)	Item	R1	R2	R3	R4	R5	R6	R7
1	Time (min)	1:00	3:00	4:00	7:00	10:00	20:15	30:27
	JTU	22	12	11	13	12	14	14
	TSS (mg/l)	75	48	46	52	48	54	54
	% Removal	43	63.5	65	60.6	63.5	59	59
2	Time (min)	1:07	3:07	4:07	7:05	10:07	20:19	30:31
	JTU	16	12	11	11	13	14	13
	TSS (mg/l)	60	48	46	46	52	54	52
	% Removal	54.5	63.5	65	65	60.6	59	60.6
3	Time (min)	1:11	3:12	4:13	7:09	10:13	20:23	30:37
	JTU	21	13	13	13	12	13	14
	TSS (mg/l)	73	52	52	52	48	52	54
	% Removal	44.7	60.6	60.6	60.6	63.5	60.6	59
4	Time (min)	1:19	3:17	4:19	7:15	10:18	20:29	30:43
	JTU	35	13	12	13	13	13	13
	TSS (mg/l)	105	52	48	52	52	52	52
	% Removal	20.4	60.6	63.5	60.6	60.6	60.6	60.6
5	Time (min)	1:29	3:23	4:25	7:20	10:23	20:35	30:50
	JTU	55	15	15	13	13	13	13
	TSS (mg/l)	145	58	58	52	52	52	52
	% Removal	-	56	56	60.6	60.6	60.6	60.6
6	Time (min)	2:13	3:32	4:37	7:30	10:32	20:56	31:00
	JTU	60	20	15	13	13	11	10
	TSS (mg/l)	151	70	58	52	52	46	43
	% Removal	-	47	56	60.6	60.6	65	67.4
7	Time (min)	2:25	3:39	4:45	7:39	10:39	21:00	-
	JTU	120	24	18	15	13	10	-
	TSS (mg/l)	250	80	65	58	52	43	-
	% Removal	-	39.4	50.7	56	60.6	67.4	-

TABLE C-20
LABORATORY FLOTATION CELL BASIC DATA
(RUN 9)

Height (ft)	Item	R1	R2	R3	R4	R5	R6	R7
1	Time (min)	1:00	5:00	10:00	15:00	20:00	25:00	30:00
	JTU	300	29	26	27	28	28	27
	TSS (mg/l)	-	104	95	98	101	101	98
	% Removal	-	35	40.6	38.8	37	37	38.8
2	Time (min)	1:07	5:05	10:05	15:05	20:05	25:05	30:15
	JTU	160	30	30	29	28	28	27
	TSS (mg/l)	-	105	105	104	101	101	98
	% Removal	-	34.4	34.4	35	37	37	38.8
3	Time (min)	1:13	5:09	10:15	15:15	20:15	25:15	30:30
	JTU	300	41	36	30	30	28	27
	TSS (mg/l)	-	130	120	105	105	101	98
	% Removal	-	18.8	25	34.4	34.4	37	38.8
4	Time (min)	1:19	5:15	10:30	15:30	20:30	25:30	30:45
	JTU	250	48	33	33	30	28	27
	TSS (mg/l)	-	150	115	115	105	101	98
	% Removal	-	6.25	28	28	34.4	37	38.8
5	Time (min)	1:27	5:20	10:45	15:45	20:45	25:45	31:00
	JTU	240	85	36	32	29	27	27
	TSS (mg/l)	-	235	120	110	104	98	98
	% Removal	-	-	25	31.3	35	38.8	38.8
6	Time (min)	1:45	5:30	11:00	16:00	21:00	26:00	31:15
	JTU	230	180	45	35	31	28	27
	TSS (mg/l)	-	-	143	118	109	101	98
	% Removal	-	-	10.6	26.3	31.8	37	38.8
7	Time (min)	1:51	5:40	11:15	16:15	21:15	26:15	31:30
	JTU	250	300	58	36	33	None	None
	TSS (mg/l)	-	-	170	120	115	-	-
	% Removal	-	-	-	25	28	-	-

TABLE C-21
LABORATORY FLOTATION CELL BASIC DATA
(RUN 10)

Height (ft)	Item	R1	R2	R3	R4	R5	R6	R7
1	Time (min)	2:00	5:00	10:00	15:00	20:00	25:00	29:30
	JTU	42	22	20	22	21	21	22
	TSS (mg/l)	135	85	80	85	83	83	85
	% Removal	15.6	47	50	47	48	48	47
2	Time (min)	2:15	5:15	10:15	15:15	20:15	25:15	29:45
	JTU	37	22	22	23	23	24	24
	TSS (mg/l)	125	83	85	87	87	90	90
	% Removal	21.8	47	47	45.6	45.6	43.6	43.6
3	Time (min)	2:30	5:30	10:30	15:30	20:30	25:30	30:00
	JTU	41	24	23	25	25	25	24
	TSS (mg/l)	130	90	87	93	93	93	90
	% Removal	18.7	43.6	45.6	42	42	42	43.6
4	Time (min)	2:45	5:45	10:45	15:45	20:45	25:45	30:15
	JTU	44	25	24	25	26	25	24
	TSS (mg/l)	140	93	90	93	95	93	90
	% Removal	12.5	42	43.6	42	40.6	42	43.6
5	Time (min)	3:00	6:00	11:00	16:00	21:00	26:00	30:30
	JTU	160	30	24	25	25	25	24
	TSS (mg/l)	-	106	90	93	93	93	90
	% Removal	-	33.8	43.6	42	42	42	43.6
6	Time (min)	3:15	6:15	11:15	16:15	21:15	26:15	30:45
	JTU	500	40	27	25	24	24	24
	TSS (mg/l)	-	130	98	93	90	90	90
	% Removal	-	18.7	38.8	42	43.6	43.6	43.6
7	Time (min)	3:30	6:30	11:30	16:30	21:30	26:30	31:00
	JTU	500	42	27	25	24	None	None
	TSS (mg/l)	-	135	98	93	90	-	-
	% Removal	-	15.6	38.8	42	43.6	-	-

TABLE C-22
LABORATORY FLOTATION CELL BASIC DATA
(RUN 11)

Height (ft)	Item	R1	R2	R3	R4	R5	R6	R7
1	Time (min)	2:00	5:00	10:00	15:00	20:00	25:00	29:30
	JTU	57	30	27	25	25	25	24
	TSS (mg/l)	-	106	98	93	93	93	90
	% Removal	-	33.8	38.8	42	42	42	43.6
2	Time (min)	2:15	5:15	10:15	15:15	20:15	25:15	29:45
	JTU	34	26	26	25	24	24	24
	TSS (mg/l)	116	95	95	93	90	90	90
	% Removal	27.5	40.6	40.6	42	43.6	43.6	43.6
3	Time (min)	2:30	5:30	10:30	15:30	20:30	25:30	30:00
	JTU	30	25	25	24	24	23	23
	TSS (mg/l)	105	93	93	90	90	87	87
	% Removal	34.4	42	42	43.6	43.6	45.6	45.6
4	Time (min)	2:45	5:45	10:45	15:45	20:45	25:45	30:15
	JTU	30	23	24	24	23	23	22
	TSS (mg/l)	105	87	90	90	87	87	85
	% Removal	34.4	45.6	43.6	43.6	45.6	45.6	47
5	Time (min)	3:00	6:00	11:00	16:00	21:00	26:00	30:30
	JTU	44	24	23	23	22	22	22
	TSS (mg/l)	140	90	87	87	85	85	85
	% Removal	12.5	43.6	45.6	45.6	47	47	47
6	Time (min)	3:15	6:15	11:15	16:30	21:15	26:15	30:45
	JTU	70	27	22	21	21	21	21
	TSS (mg/l)	19.5	98	85	83	83	83	83
	% Removal	-	38.8	47	48	48	48	48
7	Time (min)	3:30	6:30	11:30	16:40	21:30	26:30	31:00
	JTU	200	33	23	21	21	None	None
	TSS (mg/l)	-	115	87	83	83	-	-
	% Removal	-	28.2	45.6	48	48	-	-

TABLE C-23

LABORATORY FLOTATION CELL BASIC DATA

(RUN 12)

Height (ft)	Item	R1	R2	R3	R4	R5	R6	R7
1	Time (min)	2:00	5:00	10:00	15:00	20:00	25:00	29:30
	JTU	600	46	41	46	46	46	48
	TSS (mg/l)	-	140	130	140	140	140	148
	% Removal	-	34	38.8	34	34	34	30.2
2	Time (min)	2:15	5:15	10:15	15:15	20:15	25:15	29:45
	JTU	85	55	50	47	49	47	47
	TSS (mg/l)	-	170	150	145	150	145	145
	% Removal	-	19.8	29.2	31.6	29.2	31.6	31.6
3	Time (min)	2:30	5:30	10:30	15:30	20:30	25:30	30:00
	JTU	200	61	54	48	46	46	49
	TSS (mg/l)	-	185	166	148	140	140	150
	% Removal	-	12.7	21.6	30.2	34	34	29.2
4	Time (min)	2:45	5:45	10:45	15:45	20:45	25:30	30:15
	JTU	180	60	53	49	47	47	49
	TSS (mg/l)	-	180	160	150	145	145	150
	% Removal	-	15.1	24.5	29.2	31.6	31.6	29.2
5	Time (min)	3:00	6:00	11:00	16:00	21:00	26:00	30:30
	JTU	95	60	53	50	48	48	48
	TSS (mg/l)	-	180	160	150	148	148	148
	% Removal	-	15.1	24.5	29.2	30.2	30.2	30.2
6	Time (min)	3:15	6:15	11:15	16:15	21:15	26:15	30:45
	JTU	76	60	54	50	49	50	48
	TSS (mg/l)	-	180	166	150	150	150	148
	% Removal	-	15.1	21.6	29.2	29.2	29.2	30.2
7	Time (min)	3:30	6:30	11:30	16:30	21:30	26:30	31:00
	JTU	76	59	52	49	48	None	None
	TSS (mg/l)	-	180	160	150	148	-	-
	% Removal	-	15.1	24.5	29.2	30.2	-	-

TABLE C-24

LABORATORY FLOTATION CELL BASIC DATA(RUN 13)

Height (ft)	Item	R1	R2	R3	R4	R5	R6	R7
1	Time (min)	2:00	5:00	10:00	15:00	20:00	25:00	29:30
	JTU	90	66	60	50	49	45	44
	TSS (mg/l)	-	193	180	150	150	140	140
	% Removal	-	-	-	-	-	4.1	4.1
2	Time (min)	2:15	5:15	10:15	15:15	20:15	25:15	29:45
	JTU	150	55	54	47	45	42	43
	TSS (mg/l)	-	170	166	145	140	130	133
	% Removal	-	-	-	<1	4.1	11	-
3	Time (min)	2:30	5:30	10:30	15:30	20:30	25:30	30:00
	JTU	75	50	44	44	42	41	42
	TSS (mg/l)	212	150	140	140	130	130	130
	% Removal	-	-	4.1	4.1	11	11	11
4	Time (min)	2:45	5:45	10:45	15:45	20:45	25:45	30:15
	JTU	61	42	40	42	41	40	40
	TSS (mg/l)	185	130	128	130	130	128	128
	% Removal	-	11	12.3	11	11	12.3	12.3
5	Time (min)	3:00	6:00	11:00	16:00	21:00	26:00	30:30
	JTU	55	39	39	39	39	39	39
	TSS (mg/l)	170	126	126	126	126	126	126
	% Removal	-	13.7	13.7	13.7	13.7	13.7	13.7
6	Time (min)	3:15	6:15	11:15	16:15	21:15	26:15	30:45
	JTU	50	38	38	38	38	38	40
	TSS (mg/l)	150	120	120	120	120	120	128
	% Removal	-	17.8	17.8	17.8	17.8	17.8	12.3
7	Time (min)	3:30	6:30	11:30	16:30	21:30	26:30	31:00
	JTU	45	38	36	36	38	None	None
	TSS (mg/l)	140	120	116	116	120	-	-
	% Removal	4.1	17.8	20.6	20.6	17.8	-	-

TABLE C-25

LABORATORY FLOTATION CELL BASIC DATA

(RUN 14)

Height (ft)	Item	R1	R2	R3	R4	R5	R6	R7
1	Time (min)	2:00	5:00	10:00	15:00	20:00	25:00	29:30
	JTU	24	22	26	23	23	23	24
	TSS (mg/l)	82	76	88	76	76	76	82
	% Removal	44	48	39.8	48	48	48	44
2	Time (min)	2:15	5:15	10:15	15:15	20:15	25:15	29:45
	JTU	25	24	25	25	24	25	25
	TSS (mg/l)	85	82	85	85	82	85	85
	% Removal	41.8	44	41.8	41.8	44	41.8	41.8
3	Time (min)	2:30	5:30	10:30	15:30	20:30	25:30	30:00
	JTU	27	27	27	26	25	25	25
	TSS (mg/l)	90	90	90	88	85	85	85
	% Removal	38.4	38.4	38.4	39.8	41.8	41.8	41.8
4	Time (min)	2:45	5:45	10:45	15:45	20:45	25:45	30:15
	JTU	27	27	27	27	26	26	25
	TSS (mg/l)	90	90	90	90	88	88	85
	% Removal	38.4	38.4	38.4	38.4	39.8	39.8	41.8
5	Time (min)	3:00	6:00	11:00	16:00	21:00	26:00	30:30
	JTU	30	28	27	27	26	25	25
	TSS (mg/l)	100	94	90	90	88	85	85
	% Removal	31.5	35.6	38.4	38.4	29.8	41.8	41.8
6	Time (min)	3:15	6:15	11:15	16:15	21:15	26:15	30:45
	JTU	32	28	27	27	26	26	25
	TSS (mg/l)	105	94	90	90	88	88	85
	% Removal	28	35.6	38.4	38.4	39.8	39.8	41.8
7	Time (min)	3:30	6:30	11:30	16:30	21:30	26:30	31:00
	JTU	32	28	28	27	26	None	None
	TSS (mg/l)	105	94	94	90	88	-	-
	% Removal	28	35.6	35.6	38.4	39.8	-	-

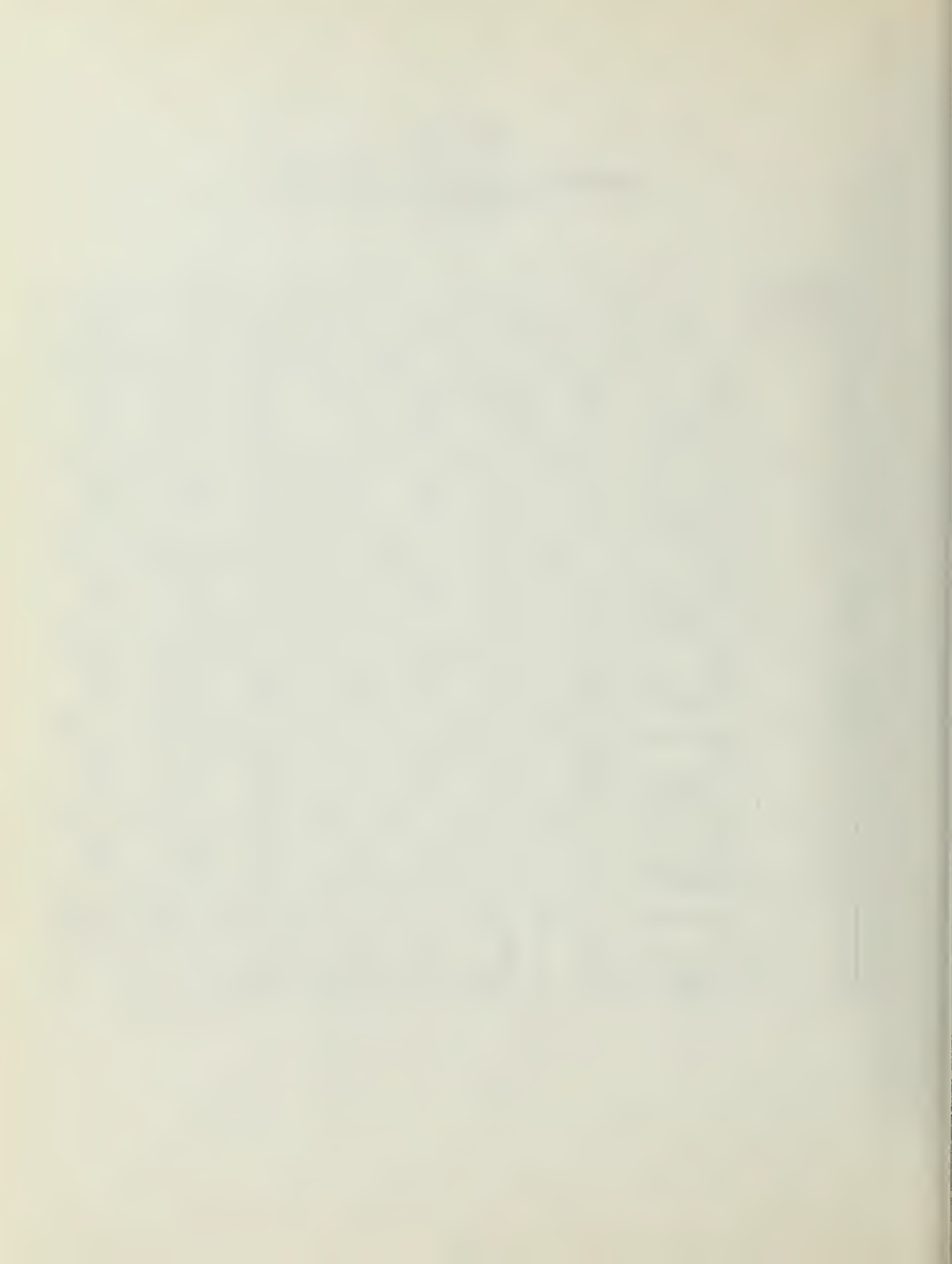


TABLE C-26
LABORATORY FLOTATION CELL BASIC DATA
(RUN 15)

Height (ft)	Item	R1	R2	R3	R4	R5	R6	R7
1	Time (min)	2:00	5:00	10:00	15:00	20:00	25:00	29:30
	JTU	32	32	34	35	36	35	34
	TSS (mg/l)	105	105	110	114	116	114	110
	% Removal	28	28	24.6	22	20.5	22	24.6
2	Time (min)	2:15	5:15	10:15	15:15	20:15	25:15	29:45
	JTU	36	34	34	34	35	34	33
	TSS (mg/l)	116	110	110	110	114	110	107
	% Removal	20.5	24.6	24.6	24.6	22	24.6	26.7
3	Time (min)	2:30	5:30	10:30	15:30	20:30	25:30	30:00
	JTU	37	35	34	34	34	34	34
	TSS (mg/l)	118	114	110	110	110	110	110
	% Removal	19.2	22	24.6	24.6	24.6	24.6	24.6
4	Time (min)	2:45	5:45	10:45	15:45	20:45	25:45	30:15
	JTU	37	34	34	34	34	33	33
	TSS (mg/l)	118	110	110	110	110	107	107
	% Removal	19.2	24.6	24.6	24.6	24.6	26.7	26.7
5	Time (min)	3:00	6:00	11:00	16:00	21:00	26:00	30:30
	JTU	36	33	33	34	34	33	33
	TSS (mg/l)	116	107	107	110	110	107	107
	% Removal	20.5	24.6	26.7	24.6	24.6	26.7	26.7
6	Time (min)	3:15	6:15	11:15	16:15	21:15	26:15	30:45
	JTU	36	34	33	34	34	34	32
	TSS (mg/l)	116	110	107	110	110	110	105
	% Removal	20.5	24.6	26.7	24.6	24.6	24.6	28
7	Time (min)	3:30	6:30	11:30	16:30	21:30	None	None
	JTU	36	33	33	33	31	-	-
	TSS (mg/l)	116	107	107	107	103	-	-
	% Removal	20.5	26.7	26.7	26.7	29.5	-	-

TABLE C-27

LABORATORY FLOTATION CELL BASIC DATA(RUN 16)

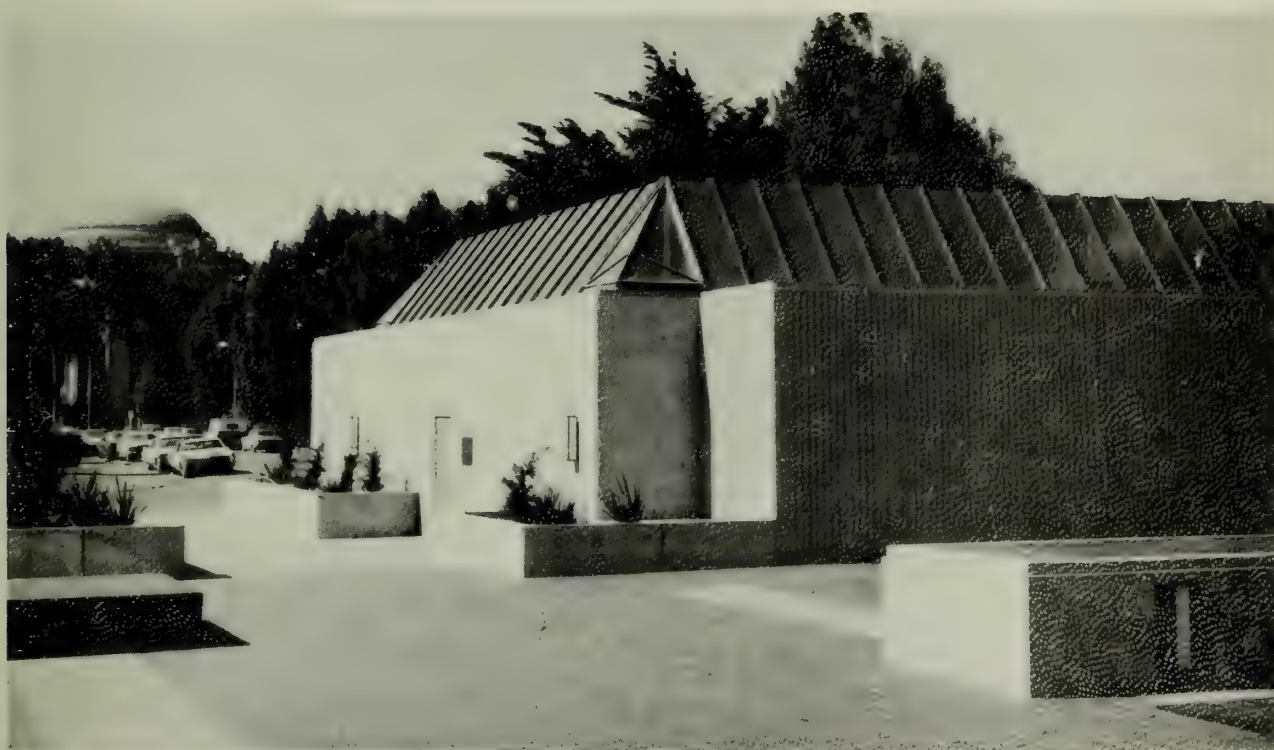
Height (ft)	Item	R1	R2	R3	R4	R5	R6	R7
1	Time (min)	2:00	5:00	10:00	15:00	20:00	25:00	29:30
	JTU	21	16	14	15	16	17	17
	TSS (mg/l)	72	58	52	56	58	62	62
	% Removal	50.6	60.3	64.4	61.6	60.3	57.5	57.5
2	Time (min)	2:15	5:15	10:15	15:15	20:15	25:15	29:45
	JTU	26	17	17	18	18	17	17
	TSS (mg/l)	88	62	62	65	65	62	62
	% Removal	39.8	57.5	57.5	55.5	55.5	57.5	57.5
3	Time (min)	2:30	5:30	10:30	15:30	20:30	25:30	30:00
	JTU	29	20	18	18	19	17	18
	TSS (mg/l)	97	70	65	65	67	62	65
	% Removal	33.6	52	55.5	55.5	54.2	57.5	55.5
4	Time (min)	2:45	5:45	10:45	15:45	20:45	25:45	30:15
	JTU	33	21	17	18	19	18	18
	TSS (mg/l)	107	72	62	65	67	65	65
	% Removal	19.9	50.6	57.5	55.5	54.2	55.5	55.5
5	Time (min)	3:00	6:00	11:00	16:00	21:00	26:00	30:30
	JTU	30	21	20	19	18	18	17
	TSS (mg/l)	100	72	70	67	65	65	67
	% Removal	31.5	50.6	52	54.2	55.5	55.5	54.2
6	Time (min)	3:15	6:15	11:15	16:15	21:15	26:15	30:45
	JTU	29	22	20	19	18	18	17
	TSS (mg/l)	97	76	70	67	65	65	62
	% Removal	33.6	48	52	54.2	55.5	55.5	57.5
7	Time (min)	3:30	6:30	11:30	16:30	21:30	-	-
	JTU	26	22	21	20	20	-	-
	TSS (mg/l)	88	76	72	70	70	-	-
	% Removal	39.8	48	50.6	52	52	-	-

APPENDIX C

DISSOLVED AIR FLOTATION

TREATMENT OF RAW AND DILUTE RAW SEWAGE WITH THE
DISSOLVED AIR FLOTATION PROCESS - A PILOT PLANT STUDY

PART OF CITY AND COUNTY OF SAN FRANCISCO'S
MASTER PLAN STUDY FOR WET WEATHER CONTROL PROGRAM



JULY 1971

ENGINEERING-SCIENCE, INC.

RESEARCH AND DEVELOPMENT LABORATORY

600 Bancroft Way Berkeley, California 94710

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DISSOLVED AIR FLOTATION

APPENDIX C

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WITH THE DISSOLVED AIR FLOTATION PROCESS--
A PILOT PLANT STUDY

Part of City and County of San Francisco's
Master Plan Study for Wet Weather Control Program

submitted by

City and County of San Francisco, California

prepared by

Engineering-Science, Inc.
Research and Development Laboratory/Berkeley

for

Environmental Protection Agency
Water Quality Office

July 1971

FOREWORD

This volume constitutes the third of seven technical appendices to the Project Report on Treatment of Combined Sewer Overflows by the Dissolved Air Flotation Process. Appendices in this series are:

- A. Phase I - Pre-Construction Studies on Quality and Quantity Relationships of Combined Sewage Flows and Receiving Water Studies at Outer Marina Beach
- B. Technical Objectives for Field Demonstration of Baker Street Dissolved Air Flotation Facility
- C. Treatment of Raw and Dilute Raw Sewage with the Dissolved Air Flotation Process - A Pilot Plant Study
- D. Design Factors for Baker Street Dissolved Air Flotation Facility
- E. Costs for Dissolved Air Flotation Facilities
- F. Characterization of the Receiving Water and Beach Intertidal Zone Environment
- G. Performance Evaluation of Baker Street Facility with Raw Sewage

Appendix C is submitted in partial fulfillment of DPW Order No. 80,480 between the City and County of San Francisco and Engineering-Science, Inc., and was supported in part by Grant WPRD-258-01-68 between the Environmental Protection Agency, Water Quality Office, and the City and County of San Francisco, Department of Public Works.

This report, prepared in limited edition for utilization in City and County of San Francisco's Master Plan study for wet-weather control, is under review for approval by the Environmental Protection Agency, Water Quality Office.

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 FLOTATOR ON PROCESS EFFICIENCY

CHAPTER I

INTRODUCTION

In October 1970 the City and County of San Francisco completed the construction to an operational status of a dissolved air flotation plant at the Outer Marina Beach for treatment of combined sewer overflows. It was originally intended that a demonstration program be conducted with this (the prototype) facility between October 1970 and March 1971. However, due to initial startup problems at the plant and unforeseen hydraulic conditions in the sewerage system and diversion structure tributary to the plant, it became evident that the demonstration program could not be conducted until sometime later in 1971.

In January 1971 the City authorized Engineering-Science, Inc. to proceed with the conduct of a pilot-scale study of the dissolved air flotation process. It was intended originally that the pilot program be conducted in parallel with the prototype program, but due to the inability to correct the aforementioned problems related to the operation of the prototype, the pilot program has been completed independent and in advance of studies at the prototype.

The completion of the pilot plant program in advance of the prototype demonstration study has provided the overall project with a broader perspective for establishing the information requirements and evaluating the results of the prototype program. The advantages of the pilot study are as follows:

(1) Pilot scale operations are designed to achieve both controlled loading and operating conditions and to permit an operating flexibility that is unattainable with the prototype.

(2) Large quantities of information can be obtained rapidly with a pilot plant for the development of process performance (response) curves and design criteria.

(3) The information base of the pilot system can be compared with that developed later for prototype operation to establish the scale-up

factors required for extrapolation of pilot-scale performance curves to prototype in subsequent applications.

(4) The fundamental data base for unit processes should be resident in pilot plant operations, not in unique prototype operation; the successful development of a universal data base is contingent upon compatibility and transferability of pilot plant information.

(5) Without pilot plant information, the boundary performance characteristics of the prototype cannot be determined other than fortuitously.

This report has been developed to describe the approach, methodology, and results of the pilot studies, and to provide preliminary operating criteria for the prototype facility.

CONDUCT

The pilot studies were initiated with the delivery of a Rex-Chainbelt Flota-Treat pilot unit 50 gpm capacity to the North Point Water Pollution Control Plant in January 1971. The pilot studies were conducted at the North Point Water Pollution Control Plant location from late February through the end of March 1971, and encompassed the mapping of the process performance curves (or response surfaces) of the dissolved air flotation process for treatment of dilute and undiluted raw sewages.

ORGANIZATION

The pilot study was performed by the staff of the Research and Development Laboratory/Berkeley, Engineering-Science, Inc., under the direction of Drs. T.G. Shea and R.M. Males, Co-project Managers. Project staff included Messrs. Osita Udoh, William Maddaus, John Stockton, and Michael Aaronson.

The assistance of Dr. A. Bagot, Superintendent of the North Point Water Pollution Control Plant, San Francisco, is gratefully acknowledged.

ACKNOWLEDGMENTS

This investigation was funded in part by the Facility Demonstration

Grant Project No. WPRD-258-01-68 of the Environmental Protection Agency,
Water Quality Office.

CHAPTER II

STUDY CONCEPT

THE DISSOLVED AIR FLOTATION PROCESS

A simplified flow sheet for the dissolved air flotation process is shown in Figure II-1. Raw waste was mixed with pressurized recycle flow either in an inlet manifold or in the inlet section of the flotation chamber. Chemicals were added to either the influent or the pressurized recycle flow to effect destabilization of colloidal particles and to aid in the formation of air-solids aggregates. Air pressurization was done by the injection of air into the suction side of a centrifugal pump. Turbulence in the piping system and the mechanical shear of the centrifugal pump served to implement the mixing and contact of air, chemicals, and solids in the process.

The inputs to the process are air, chemicals, and influent wastewater, and the outputs from the process are sludge (a dilute stream), float (a concentrated stream), and treated effluent.

Process Variables

The process parameters selected to describe the process-level inputs and outputs of dissolved air flotation were described previously in the state-of-the-art evaluation (Reference 1). Because the application of Dissolved Air Flotation in the present study relates to dilute streams (less than 1,000 mg/l suspended solids), the influent liquid loading rate was selected as the first appropriate variable. The quantification of the size, number, and character of air bubble-particle aggregates formed in the dissolved air flotation process application cannot be accomplished at the present state-of-the-art; for this reason, several implicit parameters were selected as measures of the potential for air bubble-particle formation:

(1) An A/S ratio, or ratio of mass of air added to (or released from) the system to mass of solids entering the flotation chamber.

(2) Recycle ratio, which defines the ratio of recycle flow (containing dissolved air) to influent flow rate to the flotation chamber.

(3) Suspended solids concentration in the flotation chamber.

A fourth factor requiring parameterization with respect to aggregate formation is the effectiveness of the chemical conversion processes initiated as a result of chemical addition. In order for a particle to be separated in the flotation process, it is necessary that the particle be destabilized with respect to electrical charge so that the particle can be floated in an air bubble-particle aggregate or settled by gravity. The jar test procedure was used in the present study to evaluate the effectiveness of chemical conversion and selection of chemical doses or dose ranges to be used in the pilot tests.

Selection of Control and Performance Variables

The foregoing information was used to select the appropriate control and performance variables for characterizing the performance of dissolved air flotation at the pilot scale. The control variables selected from this evaluation were as follows:

(1) Liquid loading rate to the flotation chamber (gpd/sq ft).

(2) Recycle ratio (percentage ratio of recycle flow rate to influent flow rate).

(3) Influent suspended solids concentration to flotation chamber (mg/l).

(4) Flocculator paddle speed (radial ft/sec).

(5) Skimmer speed (ft/min).

(6) Specific chemical dose (mg chemical per mg influent suspended solids).

The selection of criteria for process performance is dependent upon the objectives for the process as applied in the field. Inasmuch as the value of a "performance variable" depended upon the sampling and analytical methodology used, selection of the performance variable and methodology should be done with reference to the function which the prototype is

designed to serve. Among alternate performance variables which could be selected for evaluating dissolved air flotation performance in the prototype situation were removal efficiencies and/or final effluent values for suspended solids, turbidity, oil and grease (HEM), and floatables materials. In the present study, the performance variable selected was the removal of total suspended solids (TSS), as measured by turbidity correlated with TSS. A second performance variable, selected as an absolute standard of process performance, was that of the nonremovable solids fraction, *i.e.*, that portion of the influent TSS which is not susceptible to removal by the dissolved air flotation process under optimal treatment conditions.

A basic functional equation integrating the above variables and defining a mathematical model of the dissolved air flotation process can be represented as follows:

$$f = \frac{X_I^S - X_E^S}{X_I^S} = f^* (LLR_T, R_R, A/S, X^S) \quad (11-1)$$

where: f = efficiency of removal of TSS
 X_I^S = influent suspended solids concentration
 X_E^S = effluent suspended solids concentration
 X^S = influent suspended solids concentration to flotator
 LLR_T = total (influent plus recycle) liquid loading
 R_R = recycle ratio
 A/S = air-solids mass ratio
 f^* = "operations" function that is related to chemical dose, skimmer speed, and flocculator paddle speed

One maximal value of f can be defined which occurs at the optimal operating conditions for a particular point on the response surface defined by a given combination of LLR_T , R_R , A/S , and X^S . That is,

$$f_{OPT} = f' (LLR_T, R_R, A/S, X^S) \quad (11-2)$$

where: f_{OPT} = maximum TSS removal efficiency
 f' = optimal operations function

The probable shapes of the response surfaces (or process performance curves) for each of the variables in Equations 11-1 and 11-2 were discussed in Reference 1, and are illustrated in Figure 11-2.

Characterization

The input-output parameters used to characterize the performance of the pilot plant (Chapter III) are illustrated in the flow sheet of Figure 11-3 and the symbology is summarized in Appendix A. The input/output parameters have been combined with the process variables illustrated in Figure 11-3 to develop the following working equations for process characterization with the pilot plant:

- (1) Total liquid loading rate to flotator:

$$LLR_T = (Q_I + Q_R)/A \quad (11-3)$$

where: LLR_T = total liquid loading rate (gpd/sq ft)

Q_I = influent flow rate (gpd)

Q_R = recycle flow rate (gpd)

A = flotator surface area (sq ft)

- (2) Air/solids ratio:

$$A/S = 5.88 \times 10^{-5} \frac{Q_{AR}}{LLR_T X^S} \quad (11-4)$$

where: A/S = air-solids ratio based on dissolved air released, (lb air/lb solids)

Q_{AR} = dissolved air release rate (SCFM)

X^S = total TSS concentration influent to flotator (mg/l), (see Equation 11-5)

- (3) Feed TSS to flotator:

$$X^S = \frac{X_I^S + R_R X_R^S}{1 + R_R}$$

where: X_I^S = TSS concentration in influent (mg/l)

R_R = recycle ratio, Q_R/Q_I , expressed as a fraction

X_R^S = TSS concentration in recycle (mg/l)

(4) Dissolved air release rate:

$$Q_{AR} = 1.24 X^{AR} Q_R \quad (11-6)$$

where: X^{AR} = dissolved air released in recycle flow (lb/gal)

The procedure for determining X^{AR} is presented in Appendix B.

EXPERIMENTAL APPROACH

The general objective of the experimental approach was to document the process performance curves or the multidimensional response surface postulated for the dissolved air flotation process. Dissolved air flotation performance in the present study was viewed primarily in terms of suspended solids removal efficiency, and secondarily in terms of removal efficiencies for other wastewater constituents of specific interest in terms of receiving environment quality.

The pilot plant operations consisted of three levels of inquiry: laboratory-scale jar testing; pilot plant-scale batch tests; and pilot plant-scale continuous run tests. The jar test program was used to test on a simulation basis the efficacy of alternative chemical treatment being based on the separation achieved during a settling period in the containers used in the test. The jar test program was conducted as an on-going support test paralleling the batch and continuous run tests with the pilot plant to provide a basis for predicting or confirming the appropriate chemical treatment system (dose, pH, etc.) to be used in the tests.

The batch tests were done with the pilot plant to obtain a more accurate assessment of the effect of chemical dose on dissolved air flotation performance than provided by the jar test procedure and to determine the nonremovable solids fraction in the influent TSS. The information acquired on the nonremovable solids fractions was used to provide a quantification of the optimal effluent quality level that can be attained with dissolved air flotation under any operating circumstance, and permitted the definition of f^* under optimal circumstances.

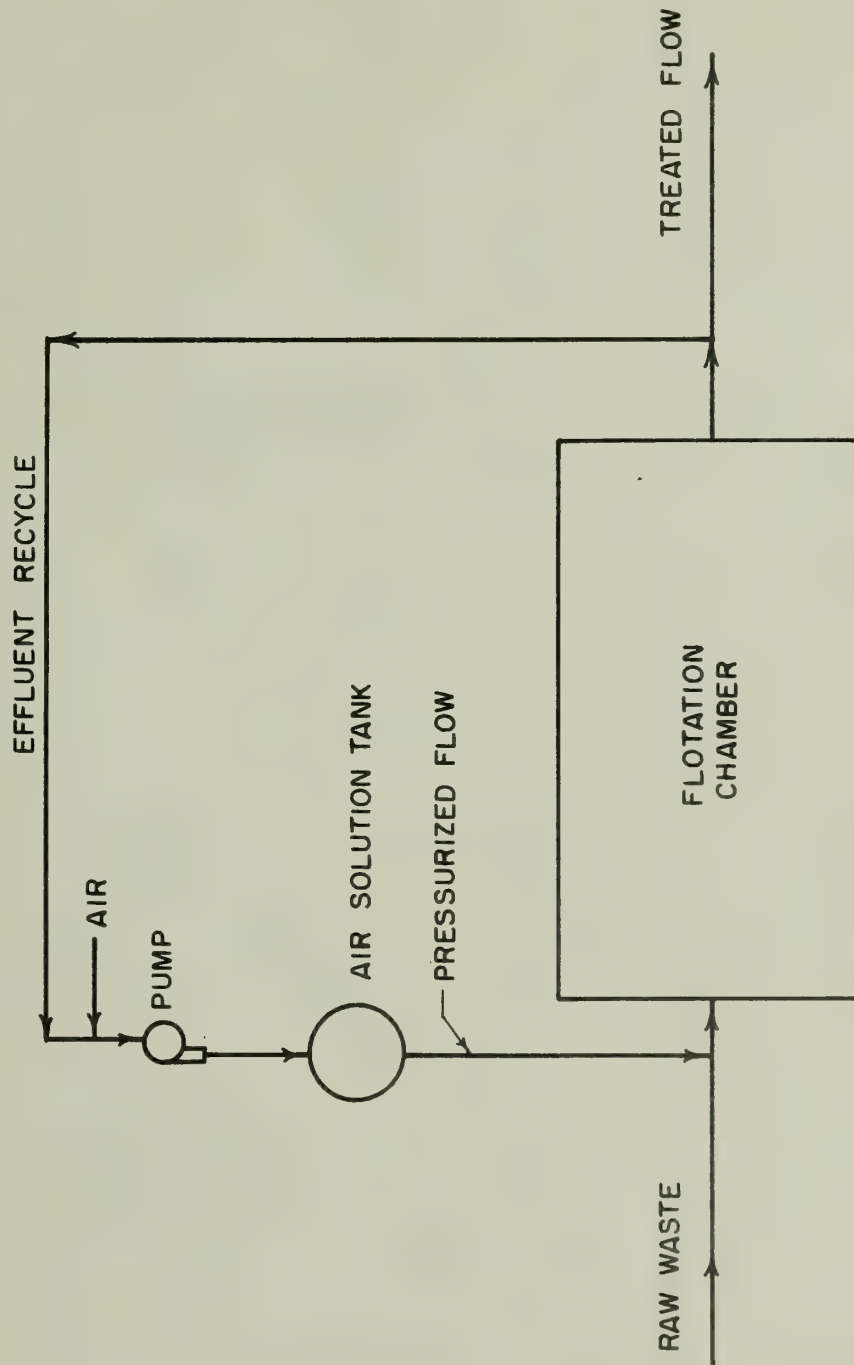
The specific objective of the continuous run program was to establish the combination of process variables at which maximum process efficiency is obtained, using as a reference boundary the optimal performance levels defined in the batch tests. A total of 23 continuous run tests were made to examine process efficiency using the range of variables indicated in Table II-1. The number of point observations (operations with a single set of process variables) used to define each response surface was based upon the postulated shape of each curve. Information on each point observation was generated by a single continuous run in which each continuous run was defined as a time period of pilot plant operation during which an effluent of stable, acceptable quality characteristics was obtained.

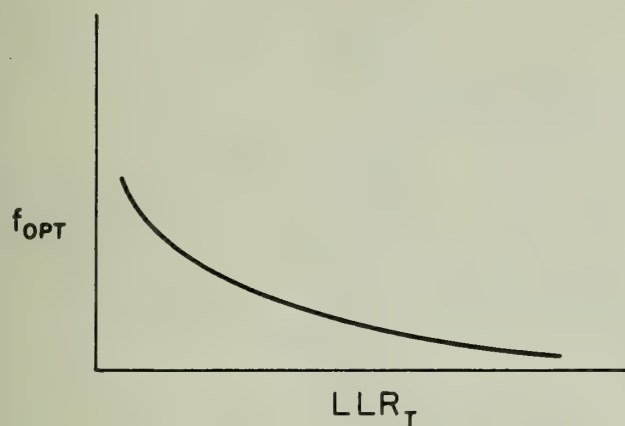
TABLE II-1
OVERVIEW OF CONTINUOUS RUN SETS
IN PILOT PLANT OPERATIONS

Variable	Range	Units
Specific alum dose	0 - 3.2	mg/mg influent TSS
Recycle ratio	20 - 130	%
Liquid loading rate	900 - 4,200	gpd/sq ft
Air/solids ratio	0.01- 0.21	lb air/lb TSS
TSS concentration entering flotator	60 - 140	mg/l
Specific polymer dose	0 - 0.65	mg/mg influent TSS
Alum/polymer combinations	0-0.9; 0-0.15	mg/mg influent TSS

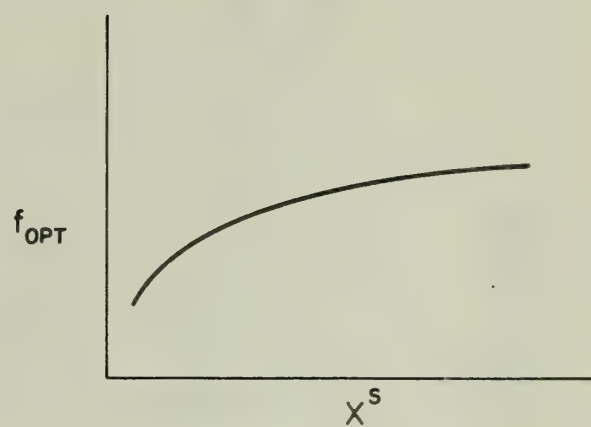
- NOTES: (1) A constant skimmer system flight travel rate of 2.0 ft/min was used in all runs.
- (2) A constant flocculator paddle speed of 1.0 ft/min was used in all runs where the flocculator was used.

FLOW SHEET FOR DISSOLVED AIR FLOTATION PROCESS

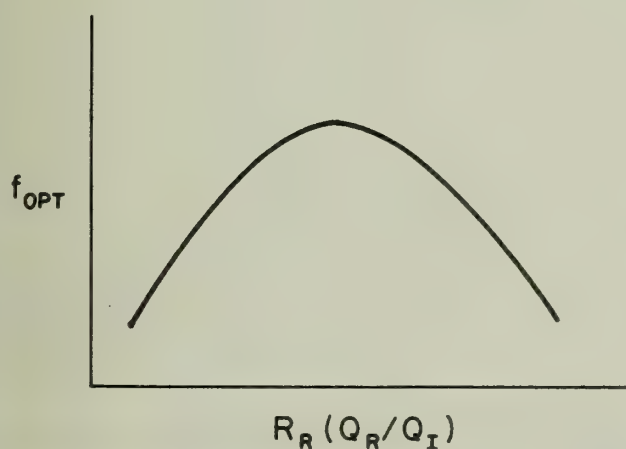




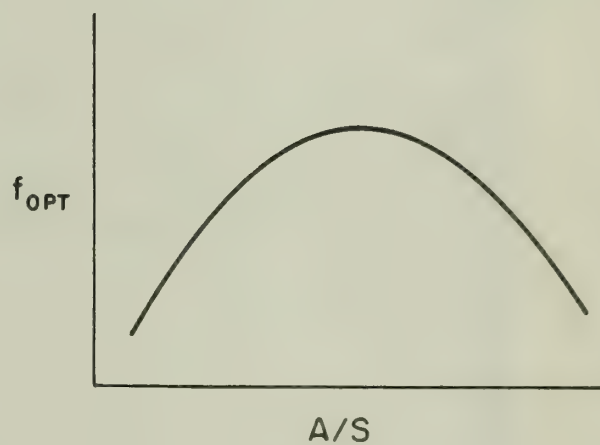
(a)



(b)



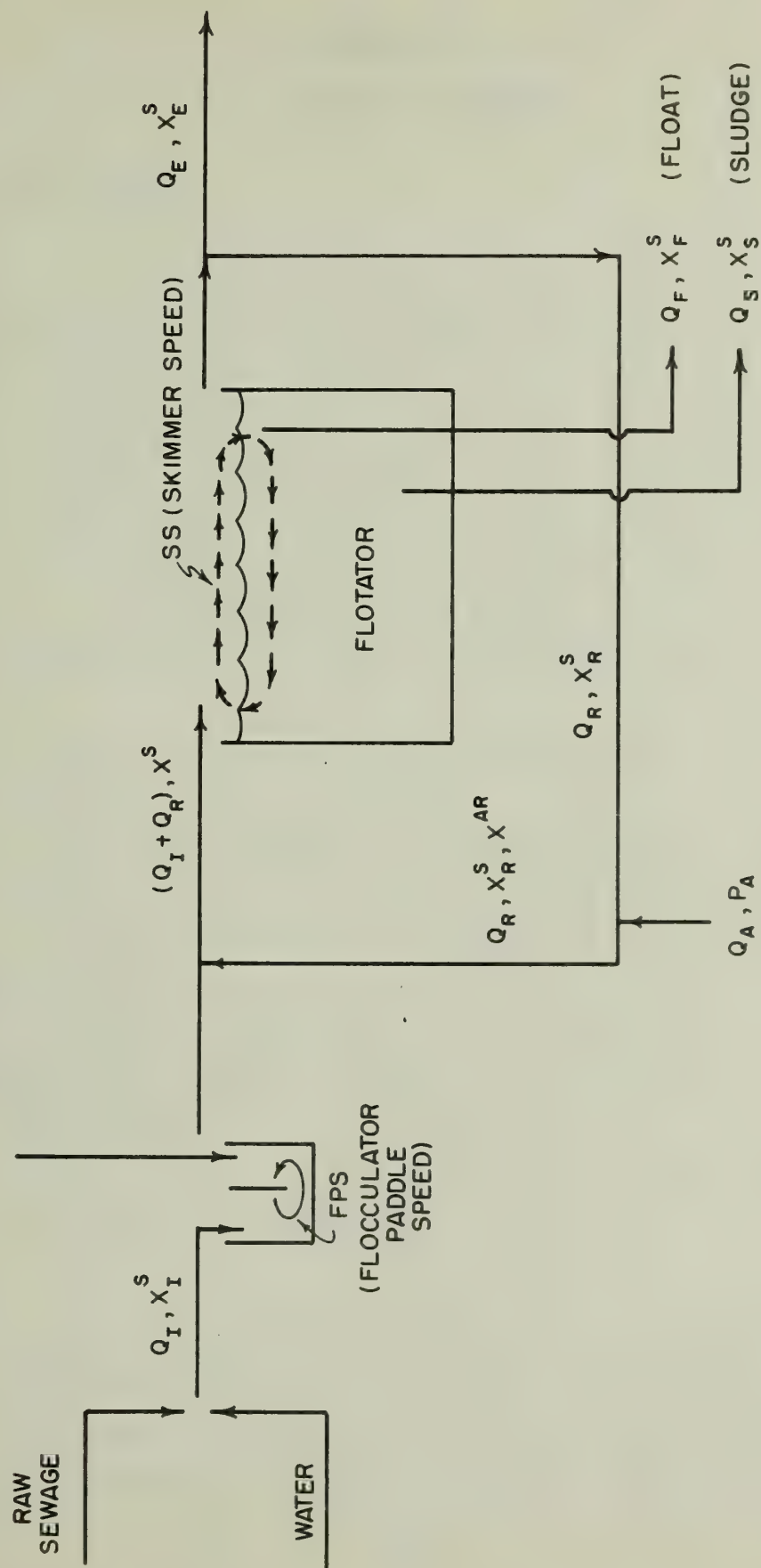
(c)



(d)

PROBABLE SHAPES OF RESPONSE SURFACES

CHEMICAL DOSES
 X_B^C (CAUSTIC)
 X_A^C (ALUM)
 X_P^C (POLYMER)



FLOW SHEET FOR
 CHARACTERIZATION OF PILOT PLANT OPERATIONS

CHAPTER III

EXPERIMENTAL PROGRAM

PILOT PLANT FACILITIES

Location

The pilot plant was located on the grounds of the North Point Water Pollution Control Plant as shown in Figure III-1 and was supplied with wastewater from the Beach Street sewer. This sewer is the main interceptor transporting wastewaters from the northerly periphery of the North Point Drainage District (including the Baker Street drainage basin) to the North Point Water Pollution Control Plant. Raw sewage from the Beach Street sewer was diluted with No. 2 treatment plant water at the pilot plant site to simulate the dilute combined sewer overflows ($\text{TSS} \leq 100 \text{ mg/l}$) that are anticipated at the prototype facility during wet weather conditions.

The Beach Street sewer is one of two major sewers tributary to the North Point Water Pollution Control Plant. Information describing the characteristics of the wastewater in the Beach Street sewer was not available at the start of the pilot program. However, a significant base of information was available describing the Water Pollution Control Plant influent characteristics, and the results of a 48-hr monitoring program of plant influent wastewater quality are presented in Figure III-2. The average suspended solids concentration in the raw sewage was 200 mg/l; a peak suspended solids level of 250 mg/l was observed at 11 a.m., and the suspended solids level varied from 200 to 230 mg/l between 12 a.m. and 9 p.m. These solids levels were typical of those observed randomly over the day in the Beach Street sewer.

Facility

The pilot plant used in the experimental program was a 50-gpm Float-Treat pilot plant (Rex Chainbelt, Inc.). A process flow sheet for the pilot plant system is presented in Figure III-3. The characteristics and components of the unit are listed in Table III-1 and the maximum hydraulic

TABLE III-1

COMPONENTS AND CHARACTERISTICS OF PILOT PLANT

Sector	Item	Description
Hydraulic Flotation Chamber	Treatment Capacity Overflow Rate Surface Area Volume Flight Speed Range Sludge	Approximately 50 gpm maximum 4,200 gpd/sq ft maximum at 20 gpm recycle flow rate 23.7 sq ft 650 gallons 0-11 fpm 2 fpm
Flocculation Chamber	Volume Paddle Speed Range	170 gallons 0-1.8 ft/sec
Recycle System	Recycle Pump Air Requirement	0-20 gpm 0.23 SCFM at 42 psig
Chemical Feed	Alum Polymer Caustic	0-500 ml/min 0-500 ml/min 0-100 ml/min

capacity of the unit is 4,200 gpd/sq ft of flotation chamber. A sketch of the dilution system used in the pilot plant is shown in Figure III-4.

The basic operational features of the pilot plant and dilution systems were as follows:

(1) The dilution system consisted of a raw sewage head tank, a diluent water head tank, a flow measuring tank, a head tank for the pilot plant feed pump, and three pumps. The dilution system was designed to permit the continuous dilution of raw sewage withdrawn from the Beach Street sewer in the pump head tank prior to transfer to the weir box of the pilot plant, which was located above the flocculation chamber.

(2) The flocculation chamber was used or bypassed (there is no flocculator system in the prototype) as desired in the treatment system. When the flocculation chamber was used in the present study, chemicals were added to the flow entering the flocculator from the weir box; when the flocculator was bypassed, chemicals were added to the stream entering the flotation chamber.

(3) Air was injected into the retention vessel in the recycle loop through an air control and pressure regulation system designed to allow a variable input up to 0.23 SCFM at 42 psig; the maximum recycle flow rate was 20 gpm, allowing the recycle ratio of 40 percent at the maximum influent flow rate of 50 gpm.

The pilot plant system was set up to parallel the operational flexibility and constraints of the prototype facility. Because the chemicals selected for use in the prototype (alum, caustic, and Dow Purifloc C-31 polymer) were also used in the pilot plant, no effort was made to evaluate process performance with other types of chemicals.

The major differences between the prototype and pilot plant systems were as follows:

(1) In the prototype, the recycle stream is withdrawn from the flotator itself at a point just under the effluent launder; in the pilot plant, the recycle stream was withdrawn from the effluent clear well.

(2) An inlet manifold is used to distribute the combined influent-pressurized recycle stream into the prototype flotator; in the pilot plant, the pressurized flow was pumped through a distributor header into the flotator wherein mixing with the influent stream was accomplished.

(3) An oscillating pipe trough and flight system is used to remove float in the prototype, whereas a beach and flight system is used in the pilot plant.

The above factors, as well as hydrodynamic scale, should be considered and evaluated when pilot plant results are compared with the results obtained with the prototype.

OPERATING AND MONITORING PROCEDURES

Jar Test Program

The jar test program was conducted according to the procedures of *Standard Methods* (Reference 2), and was done to confirm the appropriateness of selected chemical treatment systems during as well as before the pilot plant runs.

Batch Test Program

The protocol used in conducting the batch tests was as follows:

(1) The entire pilot plant system was emptied, and then refilled with dilute raw sewage influent treated with chemicals to the desired dosage and pH levels. During this period, the skimmer, recycle, and air injection systems were inoperative.

(2) The chemically treated contents of the pilot plant were then mixed for a 10-min period at a Q_R of 15 gpm to ensure homogeneity of the suspension at the start of the batch test.

(3) The batch test was commenced with the startup of the skimmer and air injection systems, followed by the total recycle of the suspension in the flotation tank for a time period until minimal additional removal of turbidity in the effluent at the clear well could be observed.

TABLE III-2
SCHEDULE OF ANALYSIS
PILOT PLANT OPERATIONS

Characteristics	Sampling Station			
	Facility Influent	Facility Effluent	Float	Solids
COD	✓	✓		
BOD	✓	✓		
Floatables	X	X	✓	✓
Oil & Grease (HEM)	X	X	X	X
Settleable Solids	X	X		
Nitrogen Forms	✓	✓	✓	✓
O-Phosphate	✓	✓	✓	✓
TSS & VSS	X	X	X	X
Total Solids			✓	✓
Conductivity	✓	✓		
Alkalinity	X	X		
Toxicity	✓	✓		
pH	X	X		
Color	✓	✓		
Turbidity	✓	✓		

NOTES: (1) X = Short Schedule.
(2) X, ✓ = Long Schedule.

An initial sample of the suspension in the flotation tank was taken during Step 2 above and analyzed in accord with the short schedule of analyses presented in Table III-2. Upon initiation of Step 3 above, samples were taken from the effluent clear well of the pilot plant (See Figure III-3) at 5-min intervals and analyzed for homogenized-sample turbidity; the homogenized-sample turbidity results were plotted continuously as the batch run progressed; when consecutive and asymptotic values of homogenized-sample turbidity were obtained (usually within 75 minutes after startup of the batch test), a final effluent clear well sample was taken and analyzed according to the short schedule. Final samples were also taken of the contents of the float and sludge hoppers and analyzed for the characteristics noted for the short schedule.

Upon completion of Step 3, the pilot plant system was operated on a continuous run basis to establish the chemical doses and pH levels desired in the subsequent batch test, and then the next batch test was conducted by repeating Steps 1 through 3 above.

Continuous Run Tests

The protocol for the continuous run tests consisted of the following steps:

(1) All process control variables LLR_T , Q_I , Q_R , X_I^S , specific chemical doses, A/S, skimmer speed, and (when used) flocculator paddle speed were set at the desired level.

(2) In parallel with Step 1, influent and effluent homogenized-sample turbidity levels were monitored at 5-min intervals until a stable effluent quality was achieved for at least a 15-min interval (*i.e.*, less than 10 percent change in effluent homogenized-sample turbidity levels over a 15-min period).

(3) In parallel with Steps 1 and 2, the effluent flow rate was monitored at 10-min intervals.

Steps 1 to 3 invariably required one to two hours of effort to achieve the desired pilot plant effluent quality (under varying conditions of influent raw sewage quality), a stable effluent quality, and the desired specific chemical dose and pH level.

When the control variables of the pilot plant had been adjusted, it was then possible to proceed to the continuous run monitoring program, which consisted of the following:

(1) A time clock was started to provide a common reference for recording all operating and monitoring activities during the run.

(2) The float and sludge hoppers were emptied and washed down, and then the outlets from these hoppers were closed to composite float and sludge samples during the run.

(3) A dissolved air release measurement was initiated at the start of the run and conducted during the run according to the procedure outlined in Appendix B.

(4) At least four sets of influent and effluent samples were taken at 10-min intervals during the run and analyzed for homogenized-sample turbidity. The results of the influent sample analysis were used to guide the adjustment of the dilution system; the results of the effluent sample analyses were used to track the stability of effluent quality. If effluent quality varied in excess of 10 percent of the average value, adjustments were made to the pilot plant system as necessary and the monitoring was continued at 10-min intervals until three consecutive effluent quality determinations meeting the 10-percent criterion were obtained.

(5) At the time when the effluent quality criterion was met:

(a) Compositing of the float and sludge samples was stopped and aliquots of float and sludge composites were analyzed in accord with the short schedule in Table III-2.

(b) The dissolved air release measurement was terminated.

(c) Influent and effluent samples were taken and analyzed in most of the runs for the short schedule and in selected runs for the long schedule presented in Table III-2.

(6) The pilot plant system was then either prepared for the next continuous run or shut down.

Analytical Procedures

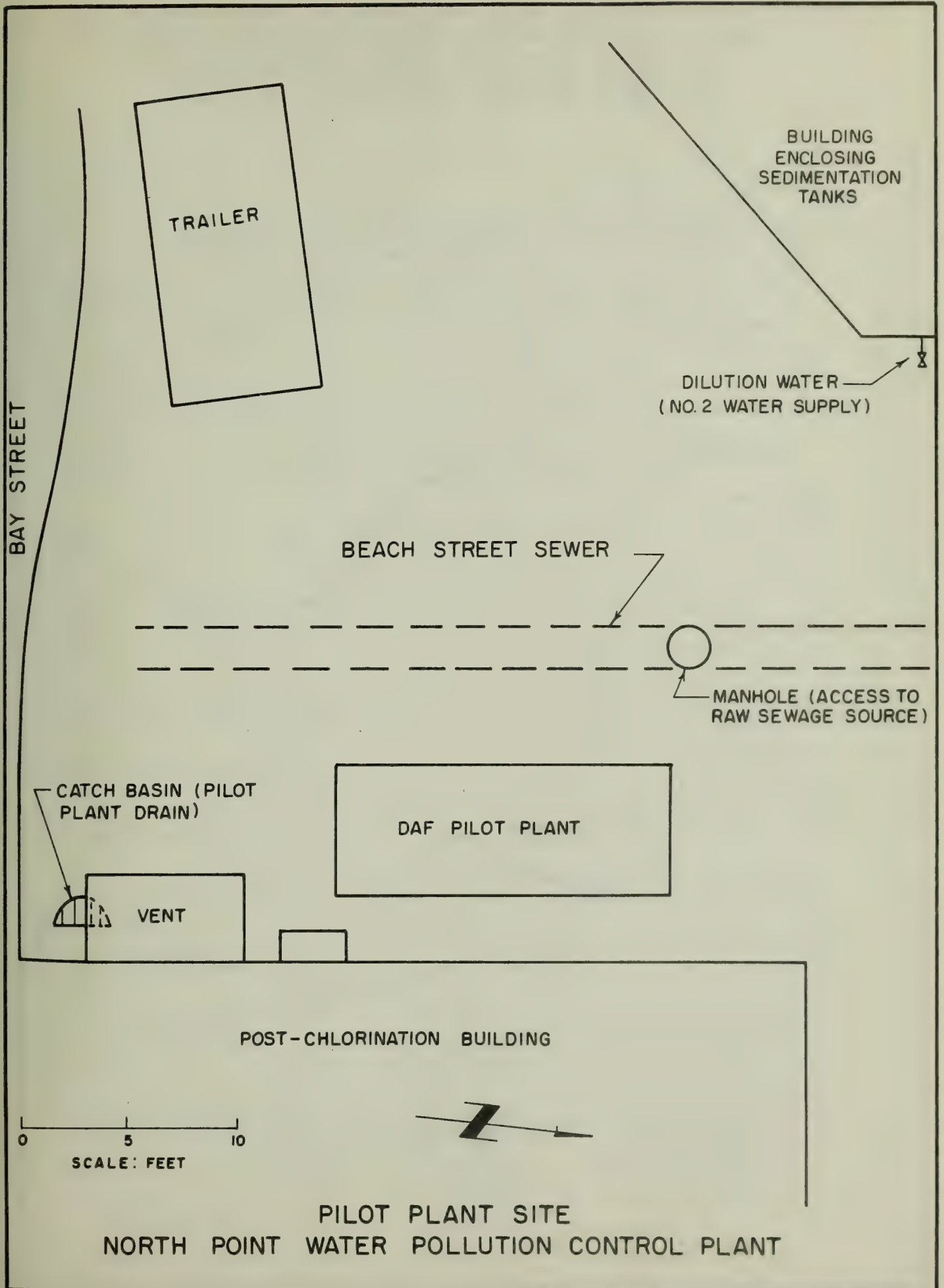
The schedule of analyses presented in Table III-2 was done using procedures presented in *Standard Methods* (Reference 2) with the following exceptions:

(1) Floatables and HEM (oil and grease) were done according to procedures developed by Engineering-Science, Inc. (Reference 3).

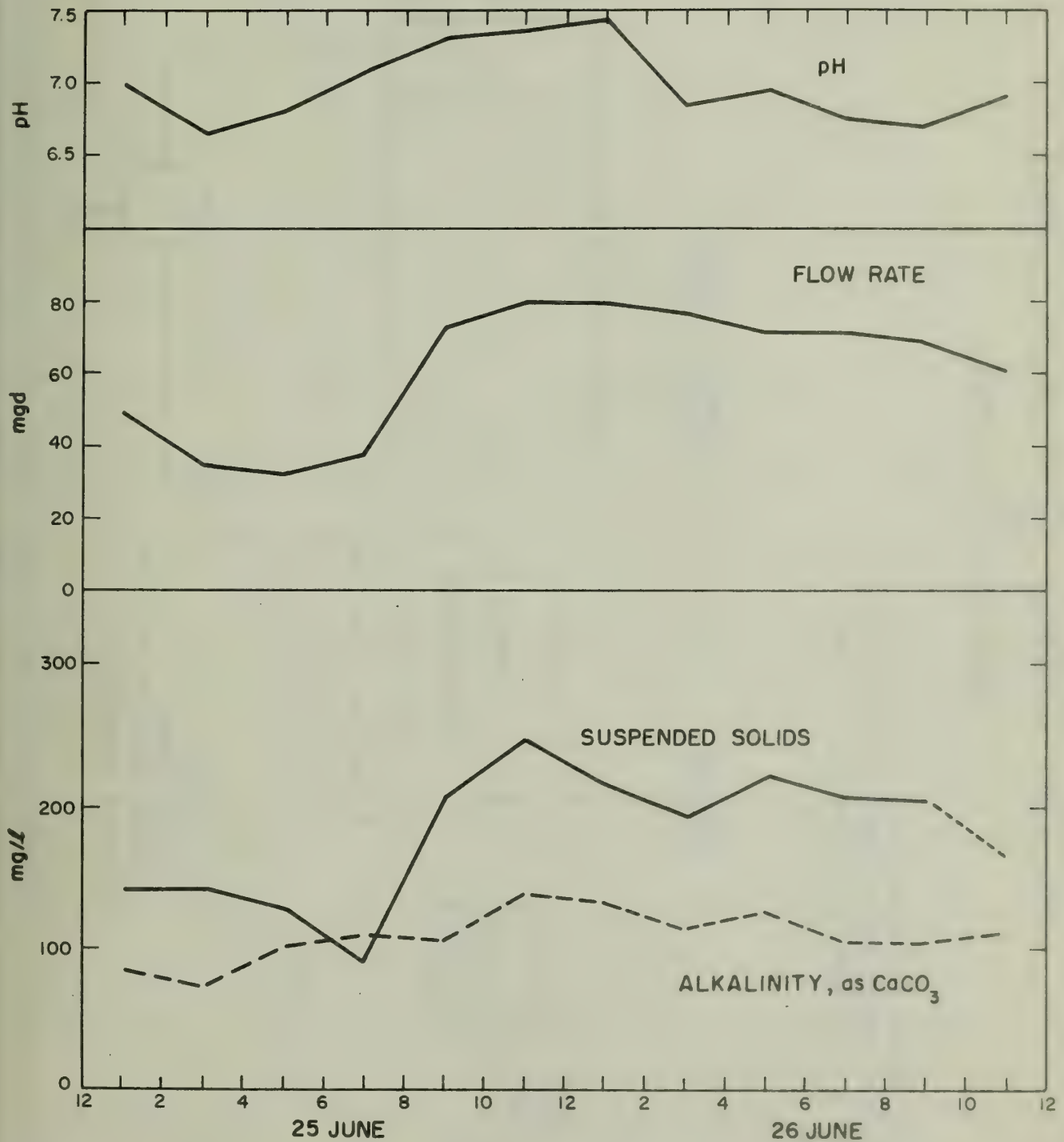
(2) Homogenized-sample turbidity was done using a Hach Model 1860 Turbidimeter and a standardized sample homogenization procedure prior to analysis. Sample homogenization was done to normalize the particle size distributions in the sample prior to the turbidity analysis.

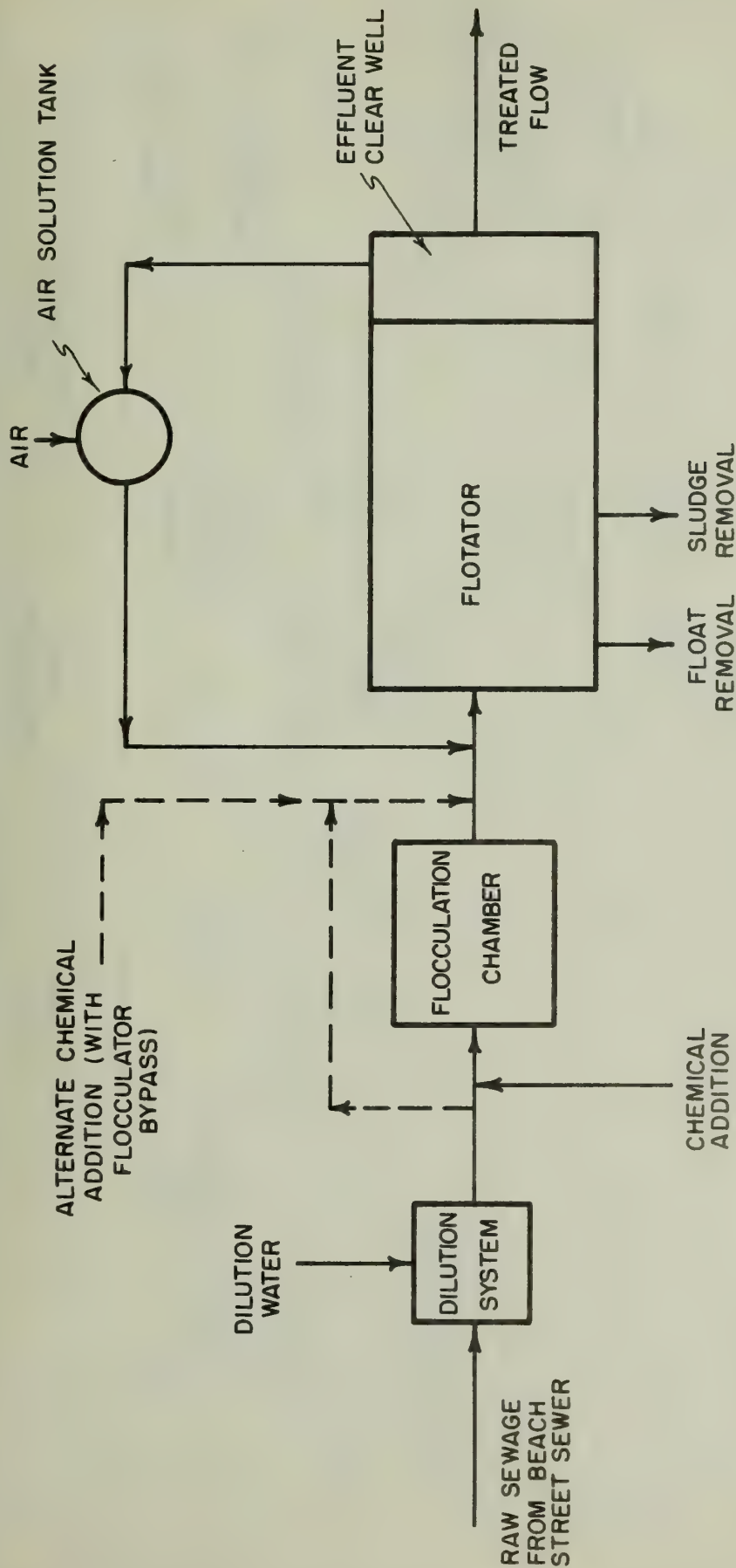
The suspended solids-turbidity correlation shown in Figure III-5 was developed using both influent and effluent samples taken during the pilot program. The correlation of Figure III-4 was used in the present study to convert homogenized sample turbidity levels to TSS values.

FIGURE III-1



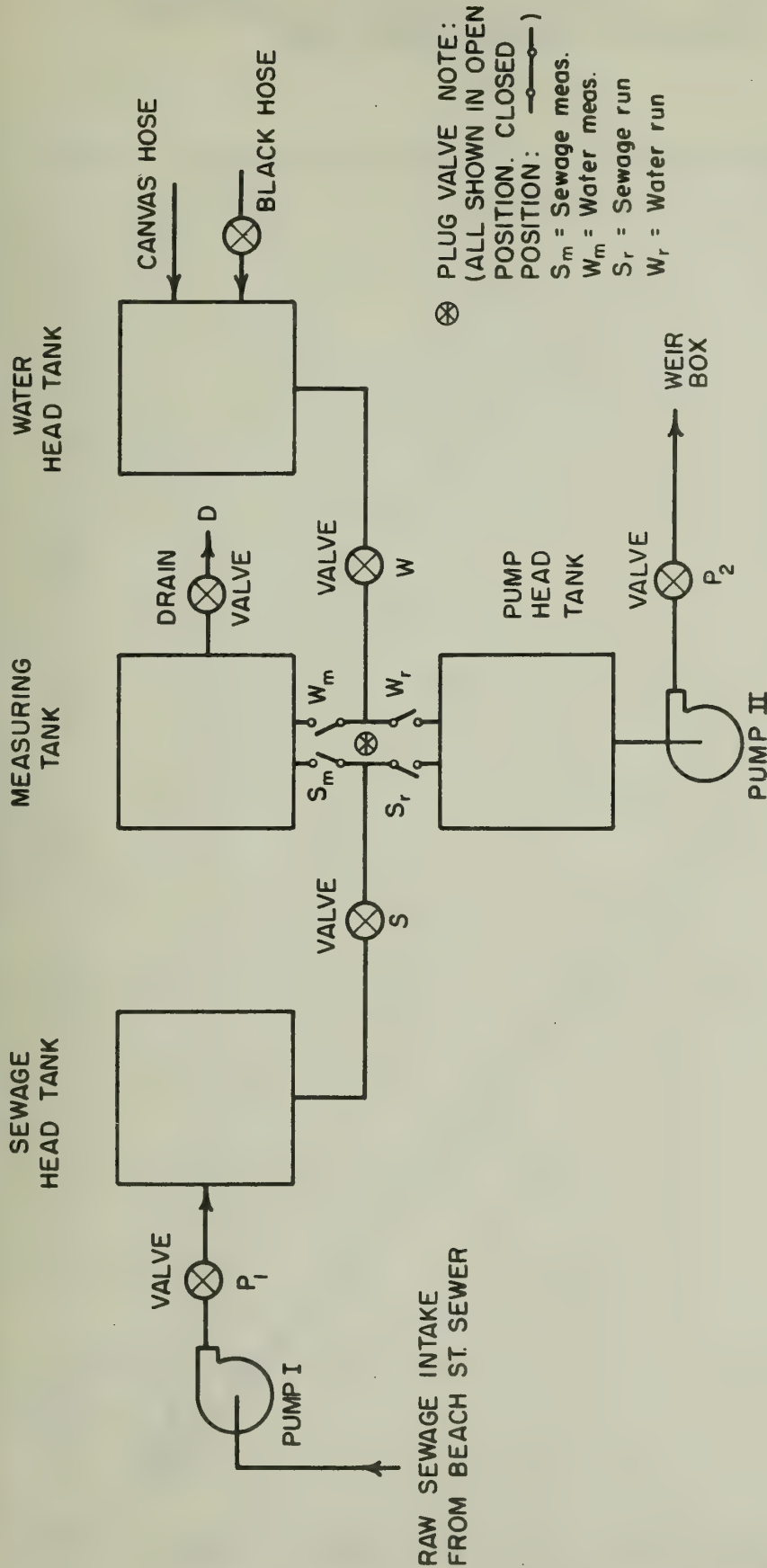
NORTH POINT WATER POLLUTION CONTROL PLANT
RAW SEWAGE GRAB SAMPLING PROGRAM
AVERAGE RESULTS OF 25 & 26 JUNE 1970





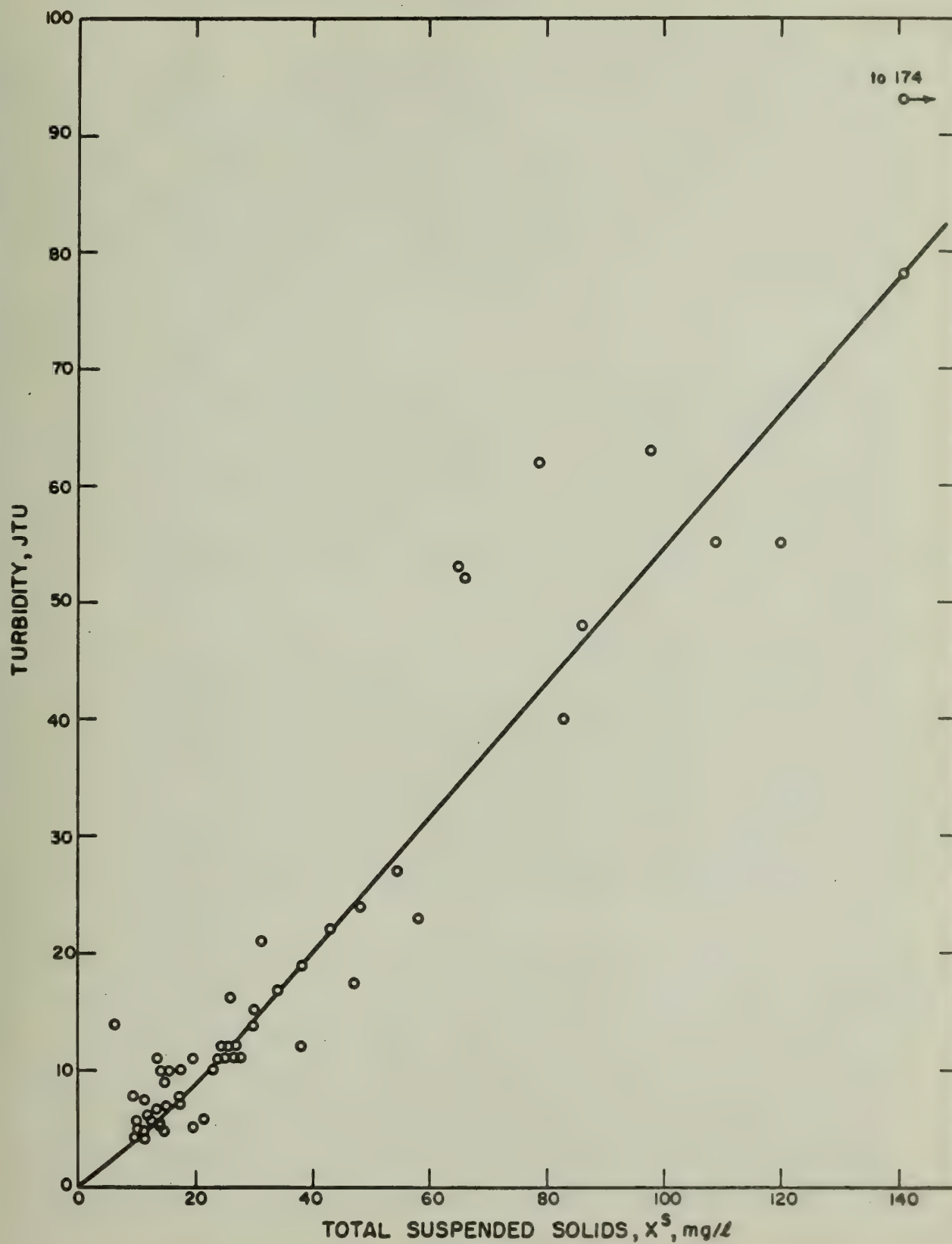
NOTES :
 Chemicals : Alum & caustic or Purifloc C-31 polymer
 Maximum liquid loading rate at 4200 gpd/sq ft of floatator
 - - - - Flocculator chamber bypass

PROCESS FLOW SHEET
 FOR
 PILOT-SCALE DISSOLVED AIR FLOTATION PROCESS
 (NORTH POINT WATER POLLUTION CONTROL PLANT - JANUARY TO MARCH 1971)



PILOT PLANT DILUTION SYSTEM

SUSPENDED SOLIDS - TURBIDITY RELATIONSHIP FOR HOMOGENIZED SAMPLES



CHAPTER IV

RESULTS

The results of the jar test program and the batch and continuous run test programs described in Chapters II and III are summarized in the present chapter. The results of the jar test program are presented first in order in this chapter, although the jar testing was conducted throughout the batch and continuous run tests as a basis for selecting or confirming the chemical treatment system to be used in each case.

JAR TEST PROGRAM

The jar test results developed with alum or polymer individually and alum and polymer in combination from the entire program have been summarized in graphical form in Figure IV-1. Over 75 individual jar tests were run using dilute raw sewages containing 40 to 100 mg/l TSS, and each data point shown in Figure IV-1 is identified in terms of turbidity removal efficiency and the final pH of the liquid in the jar test.

The dose ranges selected for evaluation in the test program varied from 0 to 3 mg alum/mg TSS and 0 to 0.6 mg polymer/mg TSS. The ranges of chemical doses were selected in conjunction with the batch and continuous run programs but also presented an opportunity for evaluating the relative merits of the different chemical treatment systems, and provided a base of information for comparing optimal jar test results with the corresponding optimal results obtained in the batch and continuous run tests.

An evaluation of the results of the jar tests done with polymer alone has indicated that an optimal turbidity removal of about 90 percent was obtained at a specific dose of 0.35 mg/mg TSS, as compared with about 50 percent removal in the control test where no chemicals were used. The optimal specific dose of 0.35 mg/mg TSS (equivalent to a dose of 35 mg/l at a TSS concentration of 100 mg/l) was from seven to 10 times greater than the optimal doses observed in previous jar tests

using Dow C-31 polymer with dilute sewages (Reference 1); test results were confirmed by repeated tests using different batches of the polymer as shown in Figure IV-1. At specific polymer doses in excess of 0.35 mg/mg TSS, turbidity removal decreased rapidly to 60 percent at 0.5 mg/mg TSS and 50 percent at 0.6 mg/mg TSS. It was apparent from visual inspection of test liquids dosed in excess of about 0.4 mg/mg TSS that a finer floc developed in these jar tests than in tests where lesser specific polymer doses were used. The reduced level of turbidity removal in the jar tests with specific polymer doses in excess of 0.4 mg/mg TSS is a manifestation of the stable suspensions that were formed at these doses.

An analysis of the results of jar tests conducted with alum alone indicated that in excess of 90 percent turbidity removal could be achieved with alum doses greater than 1 mg/mg TSS. As shown in Figure IV-1, a turbidity removal plateau of about 95 percent was obtained for specific alum doses between 1.5 and 2.5 mg/mg TSS. In excess of 95 percent turbidity removal was obtained at an alum dose of 3 mg/mg TSS, and an alum blanketing effect was observed in jar tests conducted with alum doses in excess of 2.5 mg/mg TSS. The turbidity removal results obtained with alum alone did not appear to be pH sensitive in that similar removal levels were obtained in the dose ranges tested over a final test liquid pH range of 6.5 to 7.4. As noted in a later section, this observation did not hold in the dissolved air flotation tests, where it was found that pH control in the range of 6.2 to 6.5 was critical for obtaining optimal effluent quality with the pilot plant.

The jar tests conducted with alum-polymer dose combinations were done to ascertain if economies could be achieved or turbidity reductions increased using alum and polymer in combination rather than individually for chemical conversion. It was found that in excess of 90 percent turbidity removal could be achieved over a wide range of polymer doses at alum doses of about 1 mg/mg TSS, and that about 95 percent turbidity removal was observed at an alum dose of 1 mg/mg TSS, a polymer dose of 0.3 to 0.4 mg/mg TSS, and a test liquid final pH of 6.2 to 6.5. However, the results did not indicate that a significant reduction in the doses

of either chemical was possible to achieve an optimal turbidity removal relative to that required when the chemicals were used individually. Based on the above results, and the iso-removal contours drawn in Figure IV-1, it did not appear from the jar test results that the use of alum and polymer in combination offered any advantage over the use of either chemical individually, in terms of either enhanced turbidity removal or reduced chemical dosage requirements.

It is evident from the jar test results that: (1) alum alone is effective for removing turbidity in excess of 90 percent over a broad dose range, with a minimal dose of 1 mg/mg TSS for 90 percent turbidity removal, (2) optimal turbidity removal of 90 percent was achieved with polymer in a narrow dose range at about 0.35 mg/mg TSS; and, (3) stabilized floc suspensions are obtained at polymer doses in excess of about 0.4 mg/mg TSS. It was observed that from seven- to 10-times more polymer was required (in terms of specific chemical dosages) in the present study to achieve optimal removal than was reported to be required in prior investigations (Reference 1).

BATCH TESTS

A total of four batch tests were conducted using a range of specific chemical doses varying from 1.5 to 3.4 mg/mg TSS and two liquid loading rates of 486 and 915 gpd/sq ft. It was ascertained after initial experimentation that the pH level associated with optimal solids removal was 6.2 to 6.5, and the pH was controlled within this range during all four batch tests and the subsequent continuous run tests.

The results of the batch tests are shown in Figure IV-2. The initial TSS concentration in the influent stream used to fill the flotator varied from 84 to 100 mg/l, and the initial TSS concentrations observed in the flotator varied from 30 to 110 mg/l. The initial TSS concentrations observed in the flotator reflected both the impact of the specific chemical doses and the sedimentation of solids that occurred inadvertently prior to the initial sampling. The nonremovable solids fraction was defined as the asymptotic value of the solids concentration in the flotator and was found to vary from 7 to 20 mg/l, with the higher nonremovable solids levels being associated with lower specific chemical doses. The optimal solids

removal (f_{OPT}) of 93 percent was obtained in Batch Run 3 at the specific alum dose of 3.35 mg/mg TSS, and it appeared from the results that chemical dose rather than liquid loading rate had a greater effect on the efficiency of solids removal for the range of chemical doses and liquid loading rates evaluated. The solids removal efficiency of all the batch runs varied from 76 to 93 percent and averaged 87 percent.

It is concluded from the results of the batch runs that:

(1) Under optimal conditions of batch operation, the dissolved air flotation process is capable, as an upper performance boundary, of removing in excess of 90 percent of the influent solids concentration, *i.e.*, $f_{OPT} = 93$ percent.

(2) Under batch operating conditions, process efficiency increased with increasing alum dose and with decreasing liquid loading rate for the ranges of these individual parameters tested.

CONTINUOUS RUNS

The basic information obtained in the 23 continuous run tests was analyzed using Equations 11-2 to 11-5 and the results were evaluated to document the response surfaces for each process variable in terms of TSS removal efficiency and to ascertain the efficiency of dissolved air flotation for removal of other wastewater constituents. The individual response surfaces described subsequently in this chapter have been used (in Chapter V) to define preliminary operating criteria for the Baker Street (prototype) facility.

Effect of Chemical Doses

Alum

The relationship between specific alum dose and process efficiency is illustrated by the data in Figure IV-3. The values of R_R , LLR_T , and X^S for the runs included in the analysis were within ranges in which process efficiency did not vary as a function of the individual parameters.

Process efficiency, as measured by TSS removal, was found to vary from a reference efficiency (no chemical) of 62 percent to a peak removal

efficiency of 85 percent at the maximum alum dose tested (3.1 mg/mg TSS). In all cases the effluent pH range at which optimal performance was observed at each dose was between 6.2 and 6.4, or about one pH unit less than the pH level at which optimal removals were obtained in the jar tests. The alum dose at which optimal solids removals were observed in the pilot plant (0.9 mg/mg TSS) was about 10 to 15 percent less than that observed in the jar tests.

It is apparent from the relationship shown in Figure IV-3 that with increasing alum dose the process efficiency increases to a saturation level at an alum dose of about 0.8 mg/mg TSS, and remains essentially stable thereafter with increasing alum doses. The stability of process efficiency over a wide range of alum doses is a desirable characteristic of dissolved air flotation treatment using alum for two reasons:

- (1) Less operator judgment and control capacity are required to maintain the specific alum dose (and pH) in the desired range.
- (2) It is possible to achieve a stability of process performance under a wide range of influent solids loadings such as typically experienced in treatment of combined sewage and raw sanitary sewage.

Polymer (C-31)

The relationship between process efficiency and specific polymer dose is illustrated by the data presented in Figure IV-4. Essentially constant levels of R_R , LLR_T , and X^S (similar to those used in defining the response surface for alum) were used in the runs from which data were obtained to define the relationship. In two of the eight runs (CR-21 and CR-23), the flocculator was bypassed; and in those runs for which the specific polymer dose exceeded 0.1 mg/mg TSS, the polymer concentrations were sufficient to buffer the pH of the liquid in the range of 7.3 to 7.6.

The response surface of Figure IV-4 assumes the shape that would be predicted from the jar test results, *i.e.*, a narrow range of variation of process efficiency from 60 to 80 percent was observed over the same range of polymer doses as tested in the jar test program, and peak process efficiency was observed at a specific polymer dose of

0.4 to 0.45 mg/mg TSS. The specific polymer dose required to achieve a process efficiency of 80 percent was in the order of 30 mg/l, or nearly one order of magnitude greater than that typically used in waste treatment applications. The optimal polymer dose in the dissolved air flotation process was about 20 percent greater than the optimal dose observed in the jar tests.

The results shown in Figure IV-4 do not indicate that the bypassing of the flocculator had an adverse effect on the performance of the dissolved air flotation process. In one case (Run CR-21) the process efficiency was less than indicated by the general relationship, and in the other case (Run CR-23), the opposite situation occurred.

It is evident from the results defining the response surface relating process efficiency and specific polymer dose that polymer is less efficient than alum in effecting chemical conversion in the dissolved air flotation process, and that significantly higher doses of polymer were required to effect optimum process efficiency than have been required in wastewater treatment applications elsewhere. For this reason alum was used in the continuous runs conducted to determine response surface relationships for the process variables. Also, in view of the observation that the response surface for polymer treatment defines a single dosage zone of maximum efficiency, with regions of decreasing efficiency as polymer doses are increased or decreased from this zone, it can be concluded that process efficiency is less stable with polymer treatment than with alum treatment.

Effect of Process Variables

Total Liquid Loading Rate (LLR_T)

The relationship between process efficiency and LLR_T in the dissolved air flotation process is illustrated by the data shown in Figure IV-5. The values of A/S , R_R , LLR_T , and X^S for the runs included in the analysis were within ranges in which process efficiency did not vary significantly as a function of the individual parameters. The flocculator of the pilot plant was used in seven of the eight runs and was bypassed in one run (Run CR-9).

The response surface of Figure IV-5 defines a relationship in which process efficiency decreases at a gradually increasing rate with increasing LLR_T from an efficiency of 90 percent at an LLR_T of 500 gpd/sq ft to about 65 percent at an LLR_T of 4,200 gpd/sq ft. The LLR_T of 4,200 gpd/sq ft was the maximum hydraulic capacity of the pilot plant. In comparison with the above, the maximum process efficiency observed in the batch tests was 93 percent, indicating that less than a four percent difference was observed between optimal performance levels in either test mode. The performance efficiency observed in Run CR-9 (in which the flocculator was bypassed) exceeded that observed in a parallel run (Run CR-8) in which the flocculator was used.

Several observations can be made from the results presented in Figure IV-5. In the treatment of raw and dilute raw sewages with dissolved air flotation the LLR_T can be increased nine-fold with less than 5 percent reduction in process efficiency; for this reason the dissolved air flotation process offers a degree of treatment stability that is highly advantageous for its use in the treatment of combined sewage overflows under conditions of rapidly varying hydraulic loading. At an LLR_T of 5,000 gpd/sq ft, the estimated process efficiency (based on an extrapolation of the response surface) is 50 percent, or equivalent to the typical performance level of a primary sedimentation system. However, at a 50 percent level of process efficiency, the LLR_T of the dissolved air flotation process is five to eight-times greater than typical LLR_T levels used in primary sedimentation systems. Similarly, at an LLR_T of 1,000 gpd/sq ft, the process efficiency of dissolved air flotation is 60 to 80 percent greater than is the efficiency of the typical primary sedimentation facility.

The trend indicated by the response surface of Figure IV-5 is identical to that predicted in the state-of-the-art evaluation (Reference 1) and illustrated in Figure II-2. The decrease in process efficiency as surface loading is increased may be associated with one or more of the following factors:

- (1) Destruction of air bubble-particle aggregates in the inlet structure with increasing hydraulic loading to the flotation chamber.

(2) Hydraulic overloading of the effluent launders.

(3) Breakup of float by agitation of the liquid surface in the flotator.

(4) Hydraulic short-circuiting in the flotator.

On the basis of the foregoing information it appears that the dissolved air flotation process offers several advantages over the primary sedimentation process as a solids separation process, including:

(1) An inherent stability of process efficiency over a wide range of LLR_T levels.

(2) An operational flexibility permitting the development of dissolved air flotation facilities designed to operate either at maximum process efficiency or LLR_T or at intermediate levels of either variable.

Effect of Recycle Ratio

The relationship between process efficiency and recycle ratio in the dissolved air flotation process is illustrated by the data presented in Figure IV-6. The values of R_R , A/S , LLR_T , and X^S used in the runs included in the analysis were within ranges of the individual parameters for which process efficiency was essentially constant. The pilot plant flocculator was not used in one of the four runs (Run CR-7).

The reference point on the response surface is the minimum recycle ratio of 20 percent, which corresponds to the recycle ratio incorporated in the design capacity of the prototype (Baker Street) facility. The response surface defines a relationship of increasing process efficiency at a decreasing rate with increasing recycle ratio, such that process efficiency is increased by about 10 percent as the recycle ratio is increased from 20 percent to 120 percent. The hydraulic capacity of the pilot plant recycle system precluded the investigation of process performance at recycle ratios greater than 120 percent. However, on the basis of information presented in the state-of-the-art evaluation (Reference 1) it is anticipated that process efficiency will gradually peak, and then decrease, with increasing recycle ratios

for the reasons cited above in relation to increasing levels of LLR_T .

Effect of Air/Solids Ratio

The relationship between process efficiency and air/solids ratio in the dissolved air flotation process is shown by the data presented in Figure IV-7. The values of process variables (other than A/S) used in the runs selected for the analysis were within ranges of the individual parameters in which process efficiency varied by less than 10 percent. The flocculator was used in all runs for which data are presented in Figure IV-7.

The response surface for A/S is characterized by a rapid increase in process efficiency from zero at an A/S ratio of 0.01 lb air/lb TSS to an excess of 80 percent at an A/S ratio of 0.03, followed by a gradual decrease in process efficiency to 70 percent at an A/S ratio of 0.20. The response surfaces indicate that the efficiency of the process is unstable (a large change in efficiency results from a small change in the A/S ratio) until a saturation value of process efficiency is attained at an A/S of 0.03. The saturation/decay characteristics of the A/S response surface have been observed in prior investigations (Reference 1) and have been attributed to the following:

(1) The saturation relationship is attributed to the increase in the terminal rise velocity of air bubble-particle aggregates with increasing A/S ratios.

(2) The decay relationship occurring with increasing A/S ratios beyond the saturation value of A/S has been associated with the destruction of air bubble-particle aggregates and float due to the shearing effects of turbulence caused by the release of excessive air.

Effect of Influent Suspended Solids Concentration to Flotator

The relationship between process efficiency and X^S for the dissolved air flotation process is illustrated by the data shown in Figure IV-8. The values of the process variables other than X^S for the runs included in the analysis were within ranges where process efficiency did not vary significantly as a function of the individual

parameters. The flocculator was used in both runs for which data are presented in Figure IV-8.

The response surface for X^S is characterized by an increase in process efficiency at a decreasing rate with increasing level of X^S , varying from 70 percent at an X^S of 60 mg/l to 90 percent at an X^S of 140 mg/l. The levels of X^S in Figure IV-8 at which process efficiency was documented are equivalent to levels typical, at either extreme, of combined sewage and raw sewage TSS concentrations after dilution of the influent stream with recycle flow.

An important ramification of the characteristics of the response surface for X^S is that the efficiency of the dissolved air flotation process is stable over a wide range of X^S levels. It is anticipated that this characteristic of the dissolved air flotation process will be an important advantage in application of the process for treatment of wastewaters with highly variable concentrations of suspended solids.

Effluent Quality Characteristics

Information developed on the settleable solids, HEM, floatable materials, and TSS characteristics of dissolved air flotation process effluents in all the continuous runs is summarized in Table IV-1. Data describing the total nitrogen, orthophosphate, color, BOD, COD, and toxicity characteristics of the dissolved air flotation effluents in selected runs are presented in Table IV-2. For purposes of comparison, the average values of effluent concentration and removal efficiency for each characteristic have been computed from results for the optimal performance runs conducted with each chemical and are presented in Tables IV-1 and IV-2.

The settleable solids removals (Table IV-1) were typically in excess of 95 percent for runs with both chemicals except in the case of one run (CR-12), in which the air supply was reduced below the critical level. The effluent levels of HEM averaged 8.4 mg/l in the alum runs and 15.1 mg/l in the polymer runs, and the HEM removal efficiency averaged 59 percent for the alum runs and 28 percent for the polymer runs. The efficiency of removal of floatable materials averaged 55 percent for the alum runs and 39 percent for the polymer runs, results on removal efficiency for both HEM and floatables indicate that alum was more effective than polymer in removing these constituents.

TABLE IV-1
SUMMARY OF PERFORMANCE CHARACTERISTICS
PILOT PLANT RUNS

Run	Settleable Solids		HEM (Oil & Grease)		Floatables		Suspended Solids	
	Effluent ml/l/hr	Removal %	Effluent mg/l	Removal %	Effluent mg/l	Removal %	Effluent mg/l	Removal %
CR-1	0.0	100.0	7.6	84.2	0.3	0	6.5	92.4
CR-2	0.6	91.4	4.8	54.8	-	-	16.3	87.6
CR-3	0.0	100.0	5.3	45.3	0.2	93.3	17.8	82.1
CR-4	2.0	83.3	7.9	73.4	0.3	66.7	27.4	77.5
CR-5	1.2	90.9	12.1	67.2	0.5	58.3	27.7	75.0
CR-6	<0.1	100.0	12.1	64.8	0.0	100.0	26.4	67.5
CR-7	<0.1	100.0	3.1	40.4	0.2	71.3	31.4	64.2
CR-8	<0.1	100.0	4.5	43.6	1.7	14.9	21.0	54.2
CR-9	0.4	90.0	3.9	66.6	0.3	18.2	21.3	67.9
CR-10	<0.04	100.0	6.7	71.8	0.5	45.4	42.2	63.1
CR-11	3.8	90.0	8.2	35.0	0.1	80.0	24.1	76.4
CR-12	16.0	0	20.8	12.6	1.7	0.0	103.4	0.0
CR-13	0.2	100.0	9.8	73.5	0.5	50.0	37.8	62.3
CR-14	0.2	100.0	16.4	55.6	4.7	0.0	22.1	81.0
CR-15	<0.1	100.0	16.7	26.4	5.7	0.0	27.2	73.9
CR-16	0.4	95.0	25.4	45.2	0.3	72.8	39.1	63.7
CR-17	<0.02	100.0	15.2	64.6	0.1	90.0	34.3	68.2
CR-18	<0.02	100.0	13.0	61.5	0.1	92.4	28.2	73.3
CR-19	1.6	92.0	15.7	49.9	0.3	72.1	18.4	88.4
CR-20	<0.1	100.0	13.7	0.0	0.5	78.2	22.0	82.4

TABLE IV-1 (Cont'd)

Run	Settleable Solids		HEM (Oil & Grease)		Floatables		Suspended Solids	
	Effluent ml/l/hr	Removal %	Effluent mg/l	Removal %	Effluent mg/l	Removal %	Effluent mg/l	Removal %
CR-21	0.2	94.2	13.2	76.0	0.7	68.3	31.6	70.2
CR-22	<0.1	100.0	7.3	33.0	0.3	25.0	34.3	66.2
CR-23	<0.1	100.0	5.5	9.8	0.3	70.0	28.3	74.2
AVERAGE								
Runs 1, 2, 3, 19 (Alum)	0.5	95.9	8.4	58.6	0.3	55.1	14.8	87.6
Runs 14 & 20 (Poly)	0.1	100.0	15.1	27.8	2.6	39.0	22.1	81.7

TABLE IV-2

SUMMARY OF PERFORMANCE CHARACTERISTICS

SELECTED PILOT PLANT RUNS

Run	Total Nitrogen		Orthophosphate		Color		BOD		COD		Effluent Toxicity 96-hr Survival %
	Effluent mg/l	Removal %	Effluent mg/l	Removal %	Effluent mg/l	Removal %	Effluent mg/l	Removal %	Effluent mg/l	Removal %	
CR-1	7.1	0	0.05	99.0	13	63	-	-	-	-	-
CR-2	4.9	7.4	0.07	97.0	13	35	-	-	-	-	-
CR-3	0.8	79.0	<0.02	99.0	7	79	-	-	-	-	-
CR-11	10.3	27.5	0.15	97.0	17	56	12.3	84.2	87.8	53.6	100
CR-17	9.76	17.2	0.32	96.0	20	33	62.2	58.6	140.3	52.5	-
CR-19	11.1	51.1	0.21	99.0	10	66.7	47.2	76.3	120.1	72.3	100
CR-20	6.2	15.3	10.0	9.9	17	32.0	45.0	75.0	100.3	51.7	75
AVERAGE											
Runs 1, 2, 3, 19 (Alum)	6.0	34.4	0.8	98.8	11	61.0	47.2	76.3	120.1	72.3	
Run 20 (Poly)	6.2	15.3	10.0	9.9	17	32.0	45.0	75.0	100.3	51.7	

The effluent suspended solids levels average 15 mg/l in the alum runs and 22 mg/l in the polymer runs. The average process efficiency (in terms of TSS removal) was six percent greater for the alum runs (88 percent) than for the polymer runs.

The efficiency of total nitrogen removal in the alum runs (Table IV-2; 34 percent) was over twice the efficiency of total nitrogen removal in the selected polymer run. An average of nearly 99 percent removal of orthophosphate was observed in the alum runs as compared with 10 percent removal in the polymer run, the difference being attributable to the effectiveness of alum for converting soluble phosphorus to a form separable by flotation. The efficiency of removal of color was over 60 percent in the alum runs as compared with 32 percent in the polymer run. The efficiencies of BOD and COD removals were nearly equal at 75 percent in both the alum and polymer runs, but COD removal efficiency was 72 percent in the alum runs as compared with 52 percent in the polymer run.

Effluent toxicity in the continuous runs was characterized using the 96-hr survival test. The average survival of test organisms in dissolved air flotations effluents was 100 percent in two alum runs and 75 percent in the one polymer run.

It is evident from the foregoing that alum was more effective than polymer for the chemical conversion of dissolved and colloidal materials to forms susceptible to separation by dissolved air flotation. Based on the relative effectiveness of alum and polymer in the dissolved air flotation process, it is concluded that alum is more effective than polymer when used for the dissolved air flotation treatment of raw and dilute raw sewages.

Float and Sludge Characteristics

A summary of the solids and HEM characteristics of floats and sludges sampled in each of the 23 runs is presented in Table IV-3. The averages of the solids and HEM characteristics also have been computed for four groups of runs (runs without chemicals; runs with alum doses greater than 1 mg/mg TSS; runs with alum doses less than

1 mg/mg TSS; and runs dosed only with polymer) and are reported in Table IV-3.

The average float and sludge characteristics for the four groups of runs can be viewed from two perspectives, *viz*, the impact of type and level of chemical treatment on the characteristics of the sludges and floats that were formed, and the differences in the character of the floats and sludges themselves. With respect to the former perspective, it can be observed as a trend that the concentration of TSS, VSS, (volatile suspended solids), and HEM characteristics of the floats developed in the polymer runs were less than the respective levels of TSS, VSS, and HEM floats developed in the alum runs. However, the average volatile fraction of the polymer floats (83 percent) was seven to 17 percent greater than the average volatile fractions of the alum floats.

All of the sludges had the characteristics of dilute to full-strength raw municipal sewages. The TSS levels in the sludges varied from 30 to 210 mg/l and the HEM concentrations varied from 12 to 39 mg/l.

It is apparent from the foregoing analysis that the floats developed in the operation of the dissolved air flotation process are the only concentrated waste stream of concern in managing residual wastes developed by the process, and that the characteristics of the float are a function of the type and dosage of chemical or chemicals used.

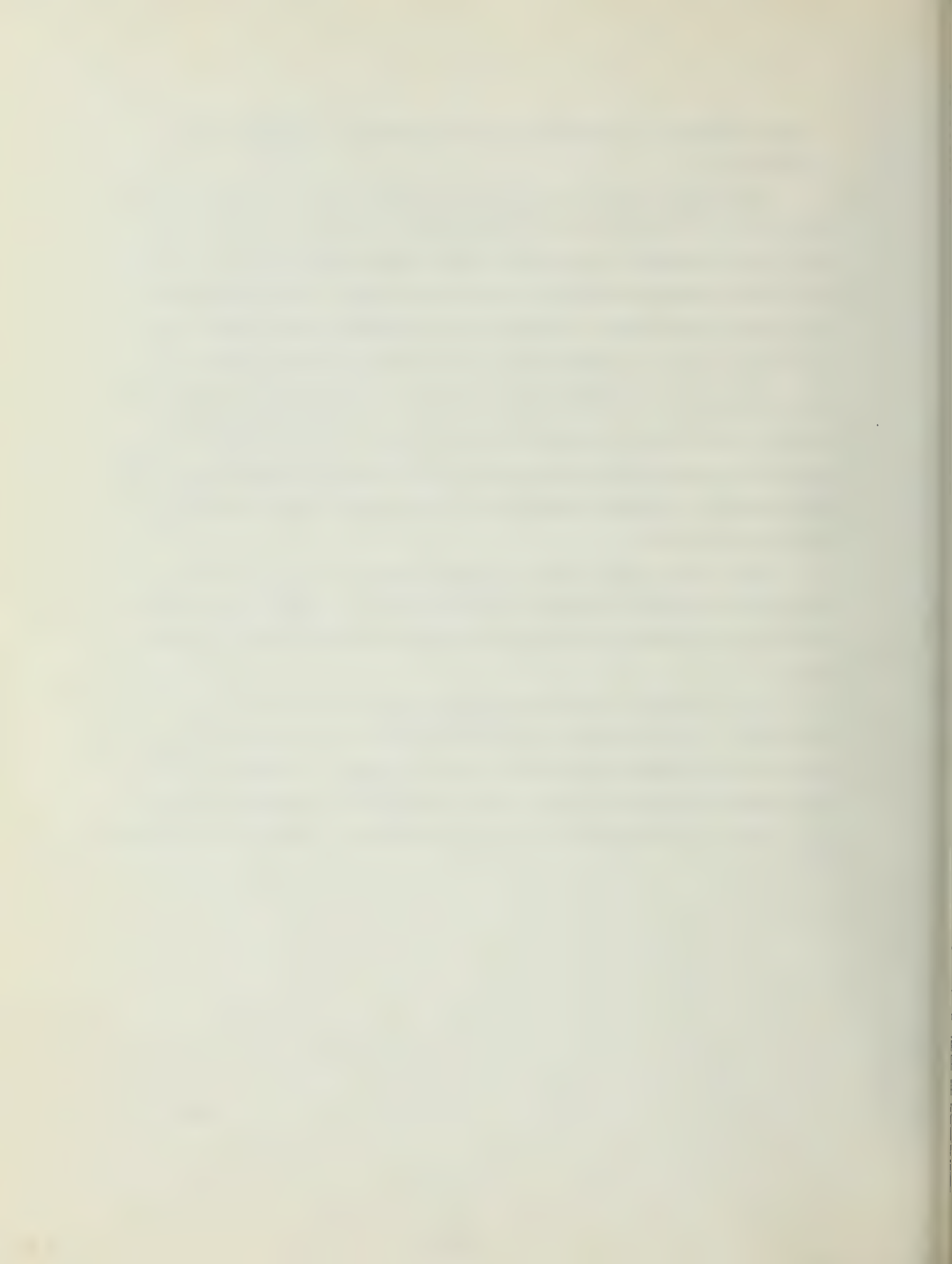


TABLE IV-3
SUMMARY OF FLOAT AND SLUDGE CHARACTERISTICS
PILOT PLANT CONTINUOUS RUNS

Run	Chemical Used and Average Specific Dose, mg/mg X_T		Float			Sludge		
	Alum	Polymer	HEM (mg/l)	TSS (mg/l)	VSS (mg/l)	HEM (mg/l)	TSS (mg/l)	VSS (mg/l)
CR-1	1.55	-	61.5	4,280	2,580	12.3	100	56
CR-2	1.50	-	286	21,600	14,600	56.7	286	180
CR-3	2.73	-	767	19,100	11,600	-	232	152
CR-4	1.29	-	207	26,100	17,300	12.8	71.5	44
CR-5	1.45	-	1,740	18,700	11,600	6.0	14.7	6.0
CR-6	1.56	-	1,390	17,100	10,700	9.4	89.3	45.4
CR-7	1.46	-	2,270	9,760	6,160	4.8	17.2	6.6
CR-8	2.72	-	180	4,510	2,720	6.1	25.0	17.0
CR-9	1.84	-	432	12,500	7,880	4.0	34.5	18.5
CR-10	-	-	1,330	3,300	2,950	23.7	83.0	22.5
CR-11	1.47	-	1,035	-	-	14.0	-	-
CR-12	0.98	-	121	376	254	93.5	620	416
CR-13	-	0.03	356	2,970	2,670	10.8	52	34
CR-14	-	0.32	229	4,850	4,330	11.4	19	17
CR-15	-	0.18	870	20,800	-	14.0	28	22
CR-16	0.68	0.08	228	4,660	3,730	14.6	106	76
CR-17	0.80	0.04	208	6,810	4,950	25.9	62	42
CR-18	0.57	0.13	261	3,530	2,760	20.9	65	52
CR-19	1.13	-	785	13,570	10,780	27.2	68	56
CR-20	-	0.45	145	3,560	3,050	26.0	46	31
CR-21	-	0.48	213	5,040	4,100	8.9	12	9
CR-22	-	0.67	51	1,430	1,150	7.8	40	29
CR-23	-	0.64	-	1,130	924	5.9	22	13
<u>AVERAGES</u>								
No Chemicals (1 run)			1,330	3,300	2,950	23.7	38.0	22.5
Alum > 1 mg/mg (11 runs)			832	14,720	9,590	15.3	93.9	58.2
Alum < 1 mg/mg (4 runs)			205	3,840	2,920	38.7	214	147
Polymer only (4 runs)			136	2,790	2,310	12.1	30	21

FIGURE IV-1

EFFECT OF ALUM AND POLYMER (PURIFLOC C-31) ON EFFICIENCY OF TURBIDITY REMOVAL JAR TEST PROGRAM

KEY:

PERCENT REMOVAL

FINAL pH

NOTE: PERCENT REMOVAL BASED
ON JACKSON TURBIDITY UNITS

CONTOURS INDICATE EFFICIENCY OF
TURBIDITY REMOVAL

SPECIFIC ALUM DOSE, mg/mg initial TSS

2.5

2.0

1.5

1.0

0.5

0.1

POLYMER DOSE, mg/mg

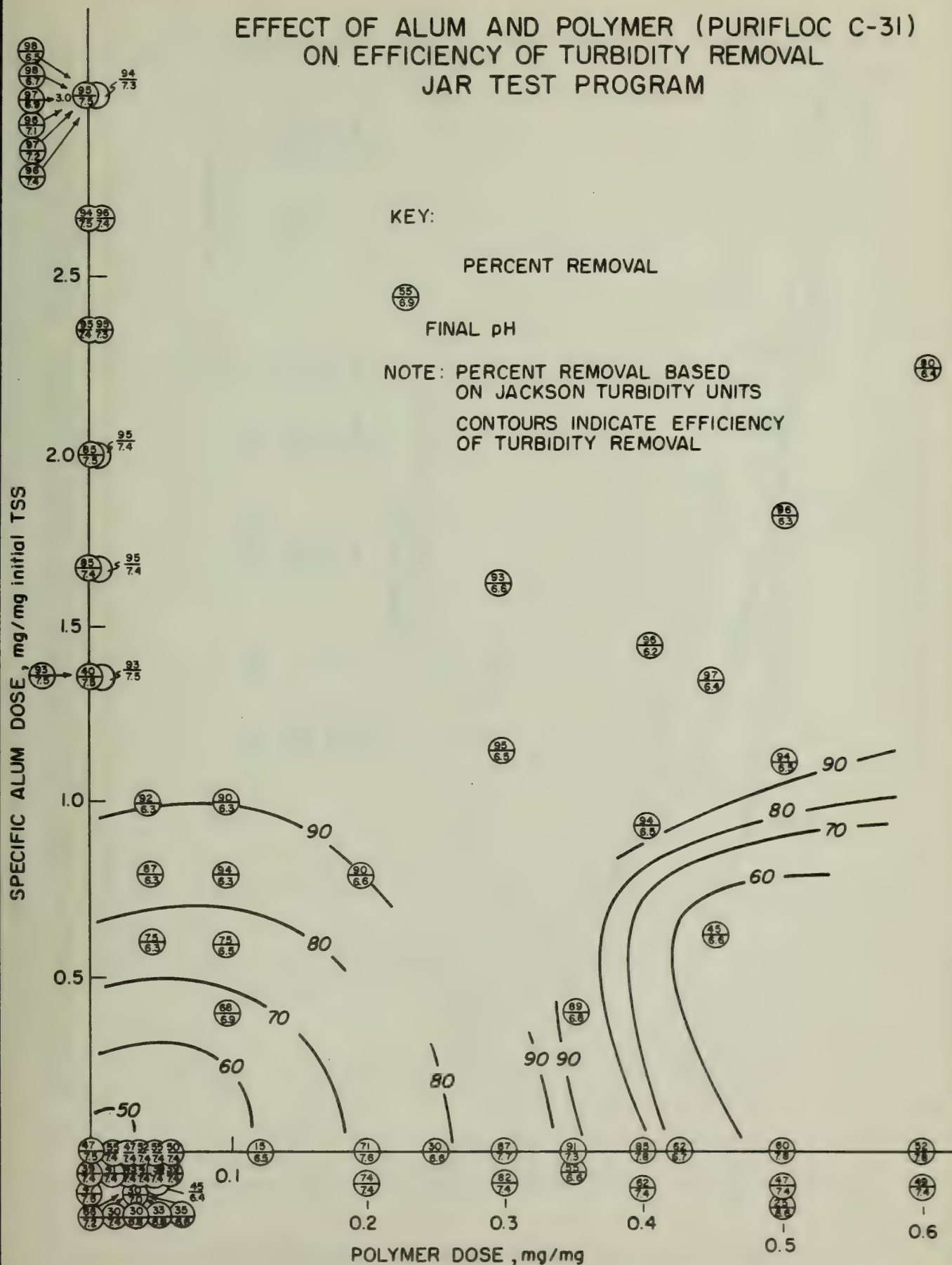
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0.3

0.4

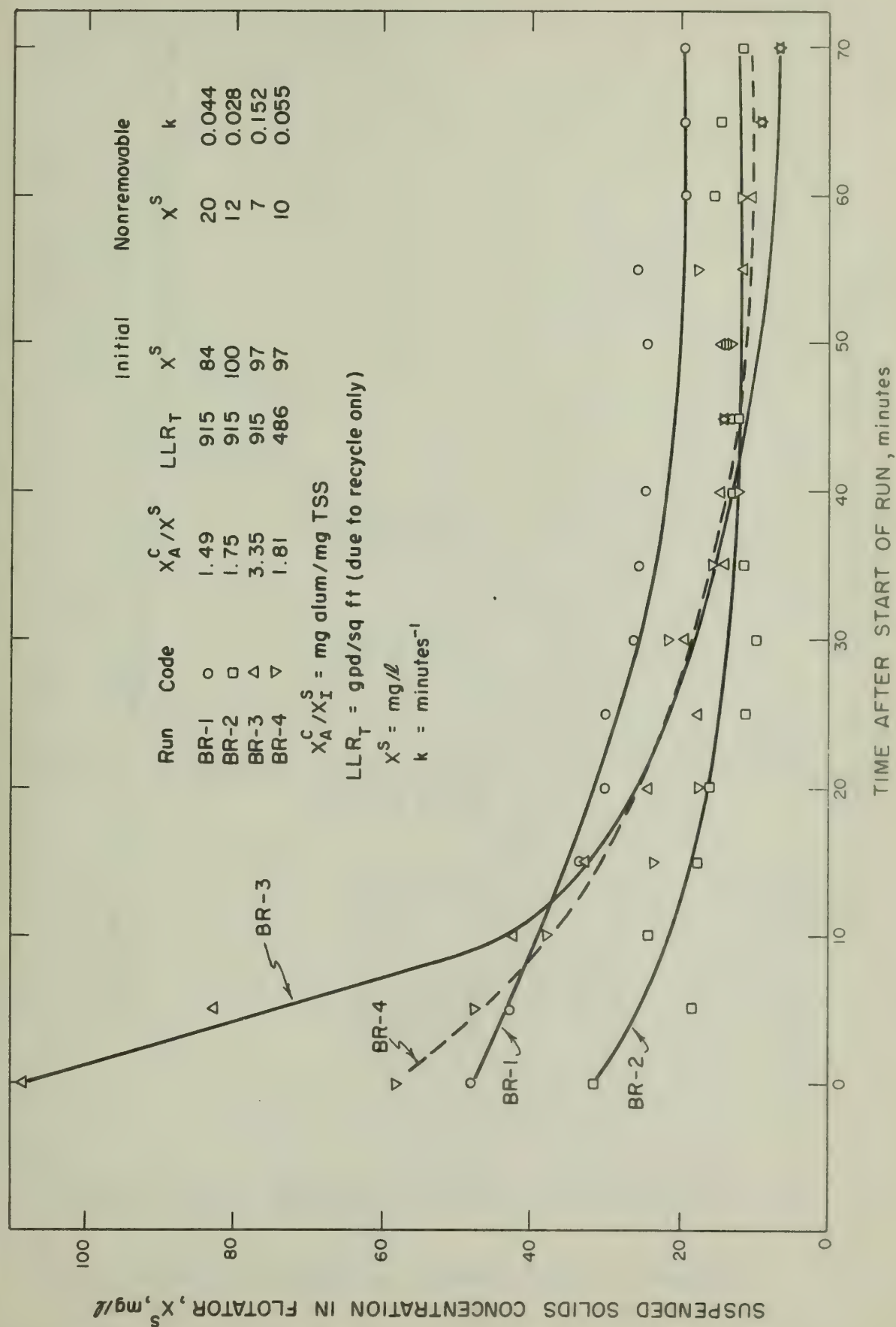
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0.6

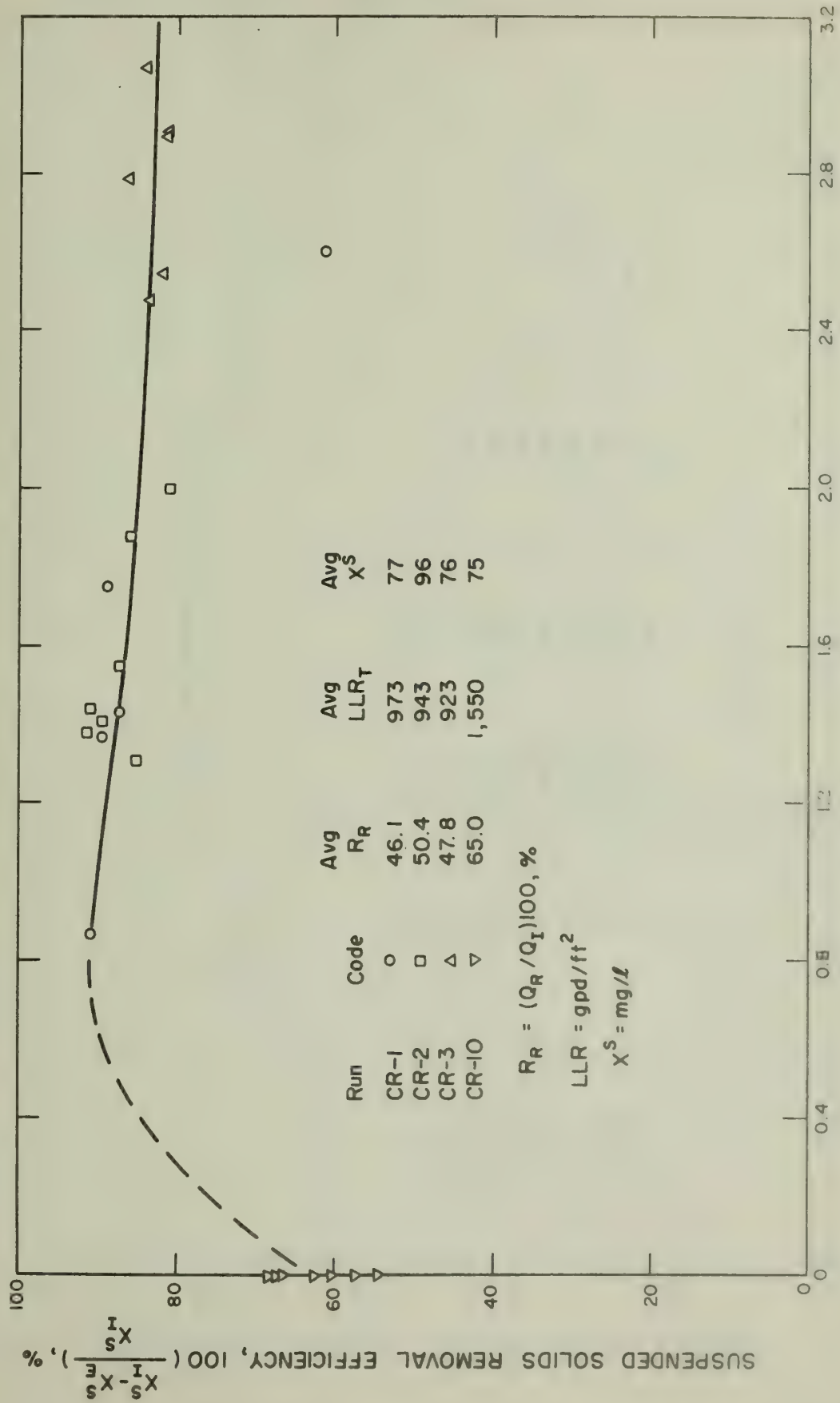




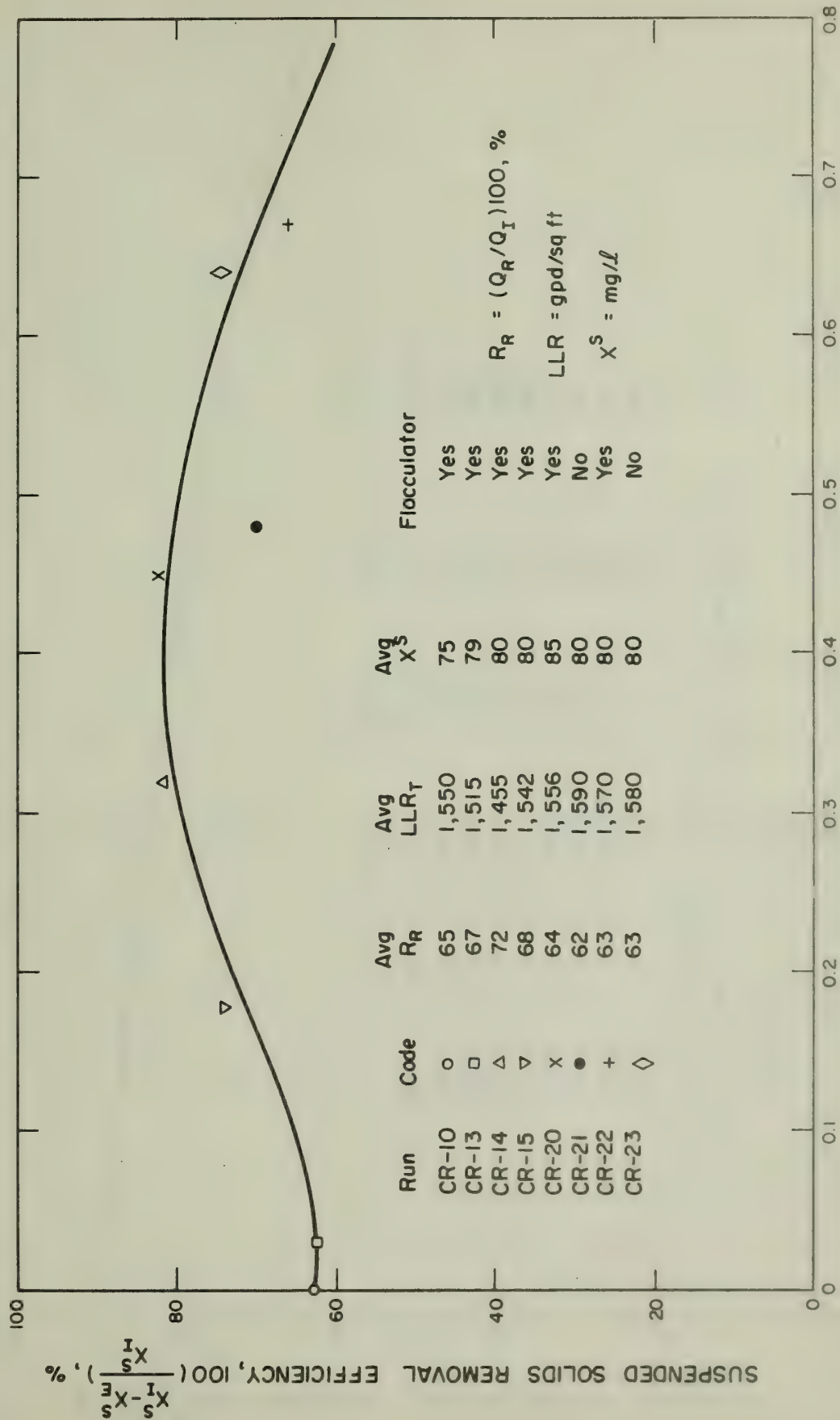
EFFECT OF SPECIFIC ALUM DOSE ON PROCESS EFFICIENCY-PILOT PLANT BATCH TESTS



EFFECT OF SPECIFIC ALUM DOSE ON PROCESS EFFICIENCY

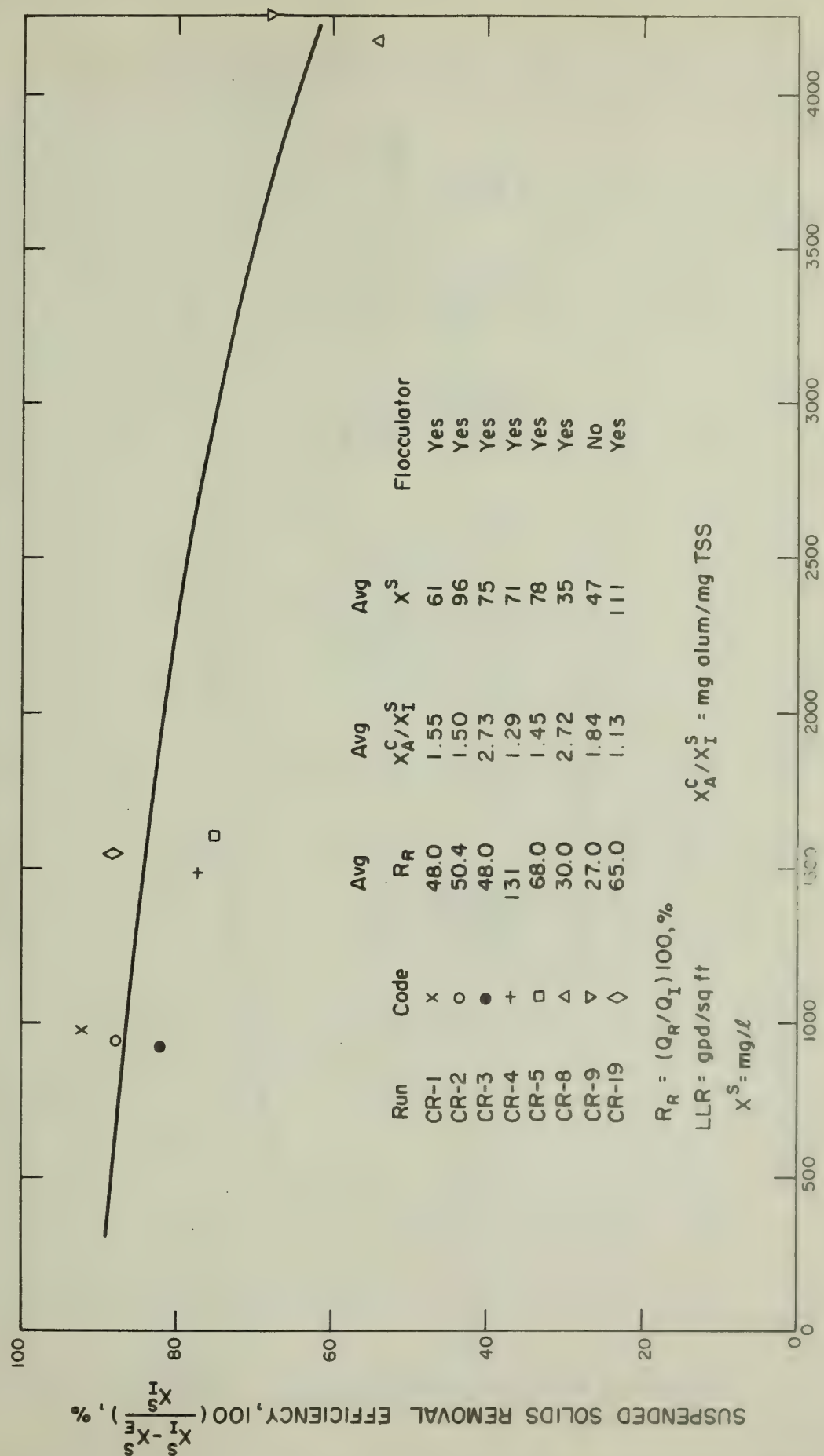
SPECIFIC ALUM DOSE, X_A^C / X_I^S , mg alum / mg suspended solids

EFFECT OF SPECIFIC POLYMER DOSE ON PROCESS EFFICIENCY

SPECIFIC POLYMER DOSE, X_P^C / X_I^S , mg Purifloc C-31 / mg suspended solids

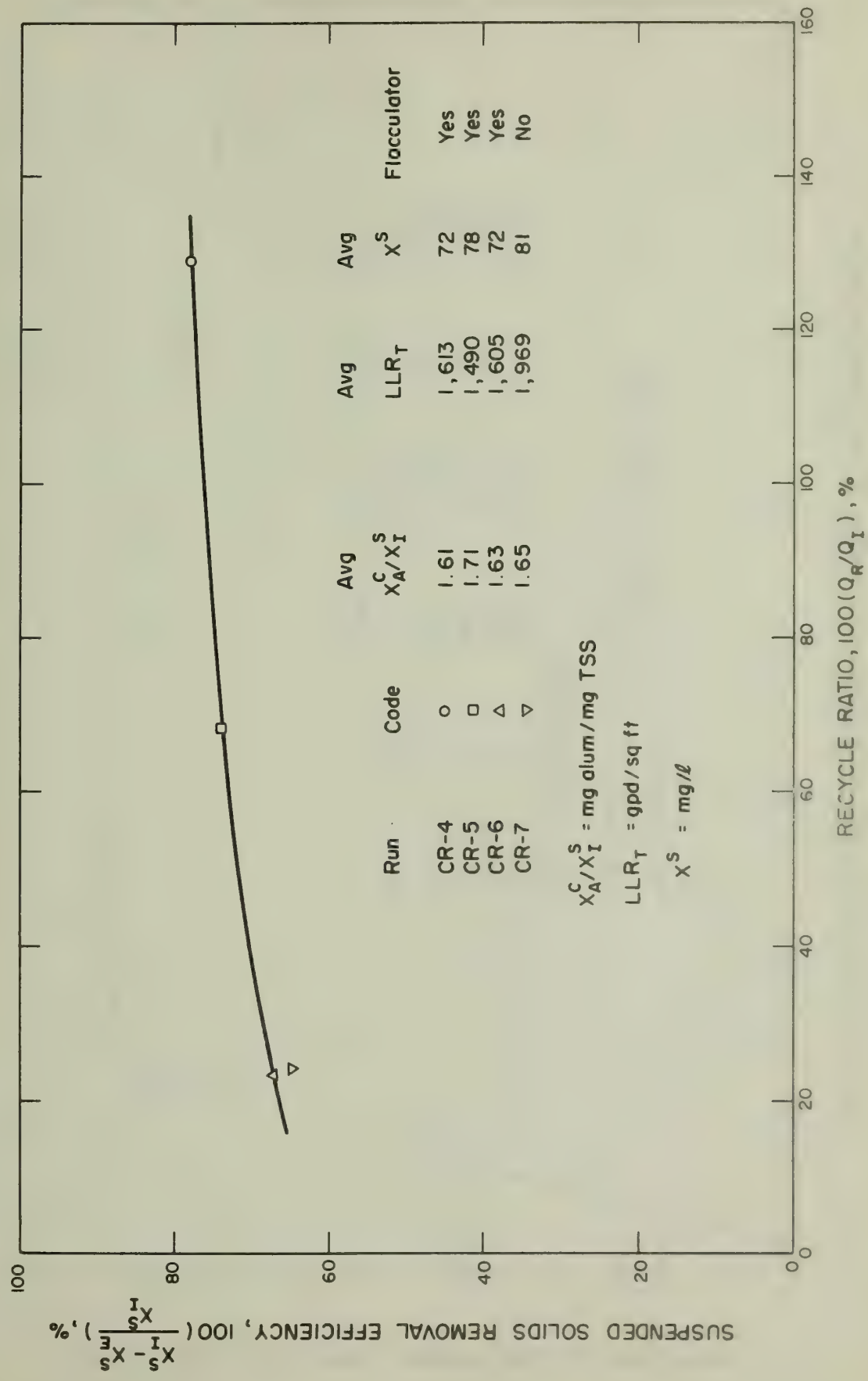


EFFECT OF TOTAL LIQUID LOADING RATE ON PROCESS EFFICIENCY



TOTAL (FLOTATOR CELL) LIQUID LOADING RATE, LLR_T , gpd/sq ft

EFFECT OF RECYCLE RATIO ON PROCESS EFFICIENCY



EFFECT OF AIR:SOLIDS RATIO ON PROCESS EFFICIENCY

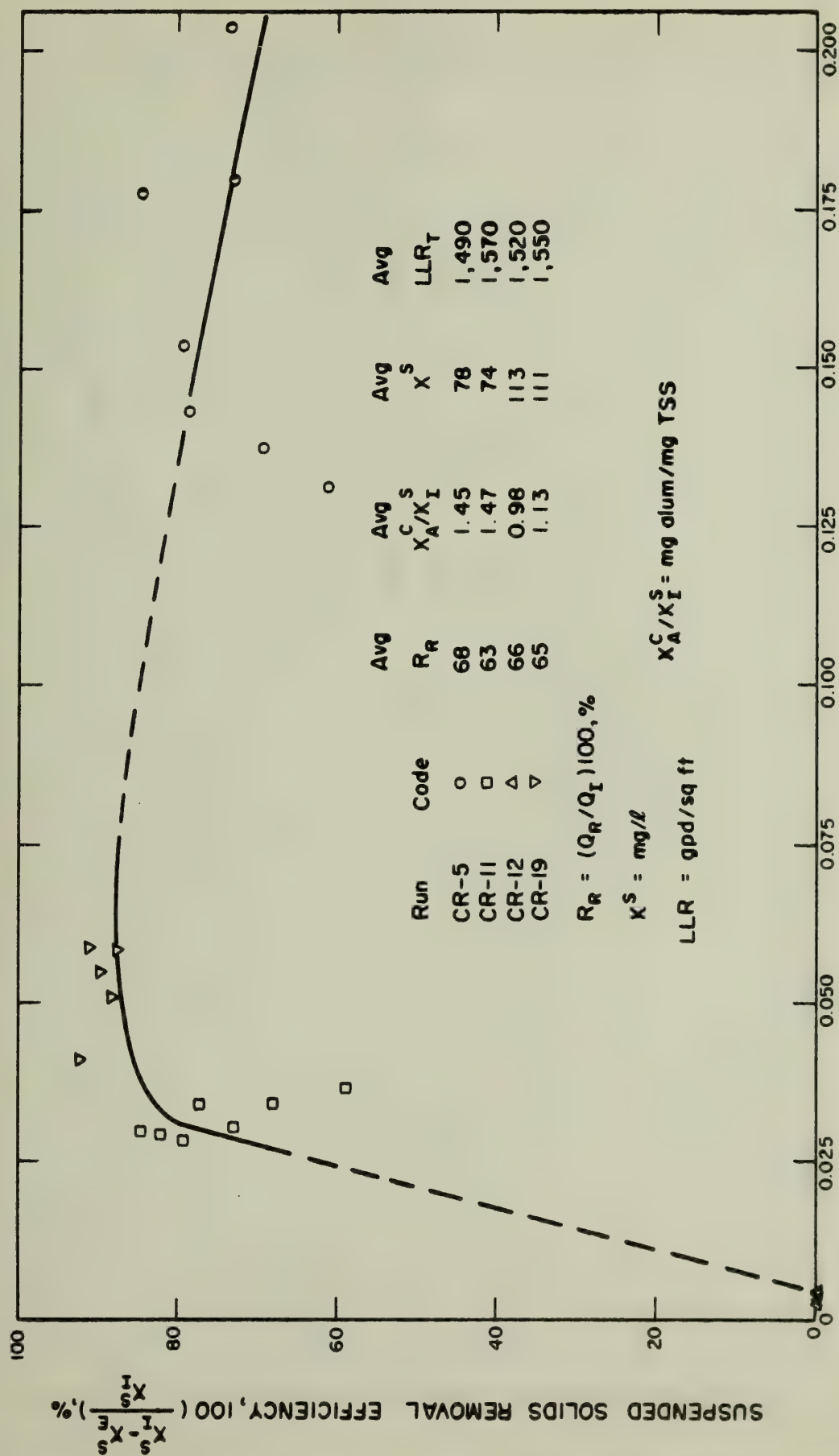
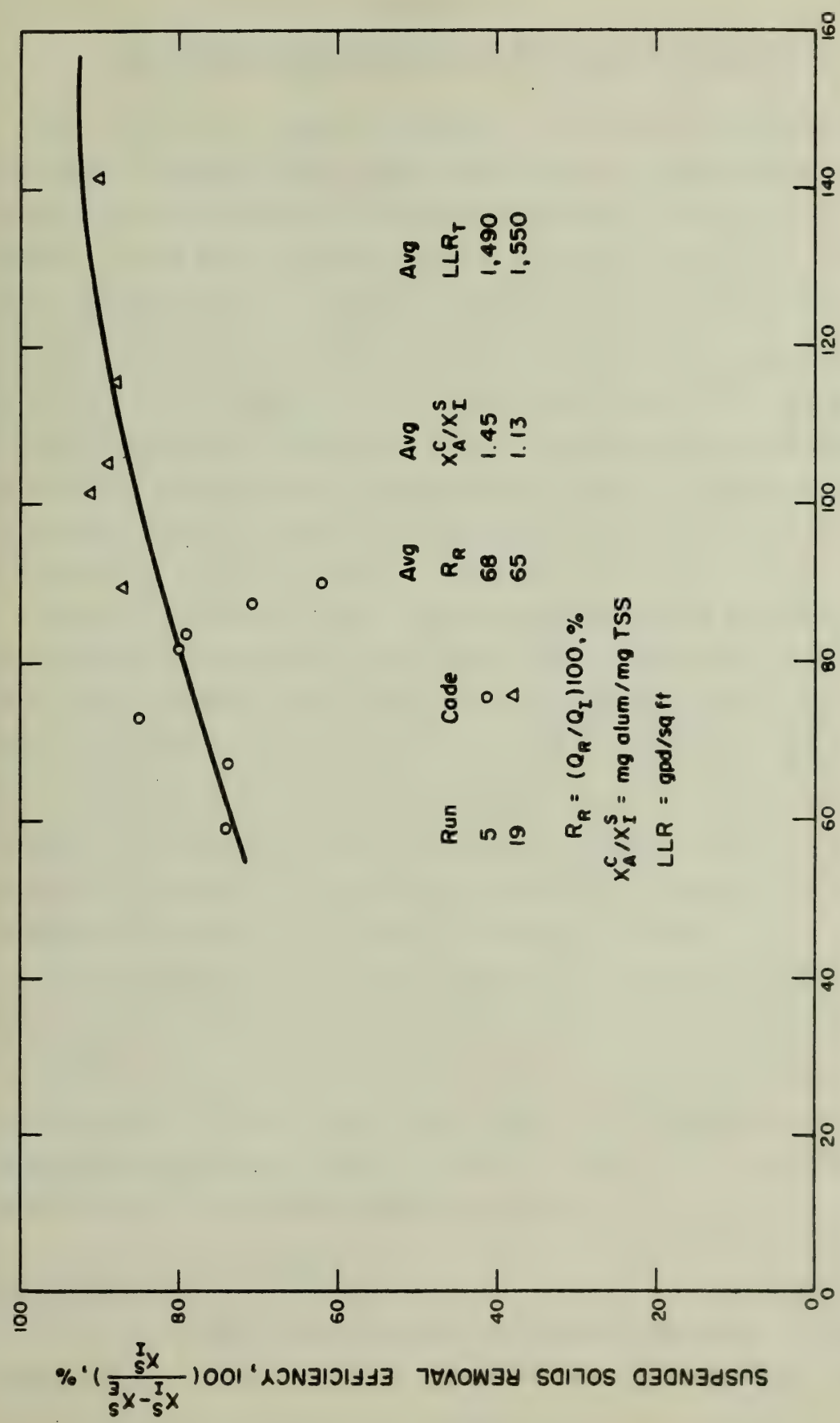


FIGURE IV - 7

AIR TO SOLIDS RATIO, A/S, lb dissolved air released / lb solids entering flotator

EFFECT OF AVERAGE SUSPENDED SOLIDS CONCENTRATION ENTERING FLOTATOR ON PROCESS EFFICIENCY



AVERAGE SUSPENDED SOLIDS CONCENTRATION ENTERING FLOTATOR, $X^S, \text{mg/L}$

CHAPTER V

PRELIMINARY OPERATING CRITERIA FOR PROTOTYPE FACILITY

The Baker Street prototype facility, with a design hydraulic capacity of 24 mgd, is presently the largest installation of the dissolved air flotation process in the world to be developed specifically for the treatment of raw and dilute raw sewages. The dissolved air flotation process has been used in a number of sludge thickening applications in the nation in the last decade, but the state-of-the-art for the application of the dissolved air flotation process for treatment of raw and dilute raw sewages is very limited (Reference 11-1). Because of this circumstance, a historical base of operating experience does not exist for the process in the latter application, and there exists no *a priori* basis for specifying how the prototype facility should be operated to achieve or approach its optimal performance capabilities.

The results of the present study have permitted the development of a response surface or set of process performance curves for the dissolved air flotation process. The response surface for the dissolved air flotation process can be used to locate zones of performance stability and the ranges of process variables that define these zones. From this perspective, the results of the present study can be used to define a region on the response surface (consisting of ranges of all process variables of concern) in which optimal process efficiency can be approached commensurate with stable process performance.

The dissolved air flotation response surface defined in the present study has been developed at the pilot scale. Consequently, pending the availability of information from the prototype demonstration program, the operating region defined by the dissolved air flotation response surface of the present study can be used to define preliminary estimates of appropriate ranges of process variables for the prototype operation, *i.e.*, preliminary operating criteria.

PRELIMINARY OPERATING CRITERIA

The shape of the response surface for the dissolved air flotation process has been characterized by the relationships presented in Figures

IV-3 to IV-8. The ramifications of these relationships on the operation of a dissolved air flotation process for treatment of raw or dilute raw sewages are as follows:

(1) Process efficiency was found to be stable with respect to alum dose for specific alum doses between 0.8 and 3.2 mg/mg TSS when alum alone was used (Figure IV-3).

(2) When polymer alone was used, process efficiency peaked at a specific polymer dose between 0.40 and 0.45 mg/mg TSS (Figure IV-4). The peak process efficiency with polymer was less than that observed for chemical treatment with alum alone; and the peak process efficiency with polymer was stable over a much narrower dosage range than was observed with alum. On this basis, polymer was not deemed as feasible as alum (when either used alone or as a coagulant aid) for the specific application of dissolved air flotation in San Francisco.

(3) In terms of LLR_T (Figure IV-5), process efficiency was found to decrease gradually from a maximum of 90 percent at an LLR_T of 500 gpd/sq ft to about 65 percent at an LLR_T of 4,200 gpd/sq ft, thus, allowing the selection of a process design to permit operation either at maximum process efficiency or at maximum LLR_T , or at intermediate levels of either variable.

(4) With respect to recycle ratio (Figure IV-6), it was observed that little advantage was gained in terms of process efficiency by increasing the recycle ratio beyond 20 percent.

(5) Process efficiency was found to be optimal in terms of the A/S ratio in the region of 0.05 lb air/lb solids, and generally stable between A/S ratios of 0.05 and 0.20 (Figure IV-7).

(6) In terms of X^S , process efficiency was found to be somewhat stable, increasing from 70 to 90 percent as X^S increased from 60 to 140 mg/l (Figure IV-8).

In contemplating an operating region of optimal performance of the dissolved air flotation process for the prototype facility, it has been assumed that the suspended solids concentration of the combined sewage flows tributary to the prototype varies between 50 and 200 mg/l, and that the average concentration is 100 mg/l. For this input char-

acteristic, and in consideration of the characteristics of the response surface, the following ranges of process variables have been selected as *preliminary operating criteria* for the prototype facility:

- (1) Alum dosage: delivered dose of 120 to 240 mg/l.
- (2) Caustic dosage: delivered dose of 50 to 100 mg/l.
- (3) Air/solids ratio: set a minimum of 0.05 lb air/lb solids for the maximum influent solids concentration.

The region defined by the foregoing variables was observed (Chapter IV) to be stable with respect to changes in the above parameters, and it is recommended that the prototype be operated using the above preliminary criteria until the results of the prototype demonstration are available.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The general conclusions of the present study are as follows:

(1) The dissolved air flotation process in conjunction with alum pretreatment is technically feasible for the treatment of raw and dilute raw sewages.

(2) In this application, the dissolved air flotation process can be operated to effect an optimal removal of in excess of 90 percent of the suspended solids in the influent stream.

(3) Given the appropriate chemical pretreatment, recycle ratio, A/S ratio, and liquid loading rates, the dissolved air flotation process can be operated to provide stable process performance over a wide range of change of process variables.

(4) The response surface design concept as described in the present report can be used to evaluate the impact of selecting alternative ranges of individual process variables in terms of the tradeoff in any number of selected performance parameters.

(5) The dissolved process offers the following advantages over the primary sedimentation process as a primary solids separation process:

- (a) An inherent stability of process efficiency over a wide range of liquid loading rates.
- (b) An operational flexibility permitting the development of dissolved air flotation facilities designed either to operate at maximum process efficiency or to trade-off process efficiency for increased level of liquid loading rate.

The specific conclusions of this study are as follows:

(1) Under optimal conditions of batch operation, the dissolved air flotation process is capable, as an upper performance boundary, of removing in excess of 90 percent of the influent suspended solids

concentration.

(2) Based on the results of the continuous run tests with the pilot plant:

- (a) With alum pretreatment and flotator pH control in the range of 6.2 to 6.4, process efficiency (as measured by TSS removal) remains stable in the dosage range of 0.8 to 3.2 mg/mg TSS.
- (b) Polymer pretreatment, when used either alone or in conjunction with alum, is less feasible than chemical pretreatment with alum alone in terms of both optimal process efficiency and stability of process performance.
- (c) Stable performance can be attained from the dissolved air flotation process at a recycle ratio greater than 20 percent.
- (d) The critical A/S ratio at which optimal process efficiency can be attained is 0.03 lb air/lb solids; process performance is stable over a range of A/S from 0.03 to 0.12 air/lb solids.
- (e) Process efficiency is stable over a range of concentrations of influent suspended solids to the flotator varying from 60 to 140 mg/l.
- (f) Alum is more effective than polymer for the chemical conversion of dissolved and colloidal materials to forms susceptible to separation by dissolved air flotation.
- (g) The float developed in the operation of the dissolved air flotation process is the only concentrated waste stream emanating from the process; under conditions of proper process operation, sludge (underflow) from the dissolved air flotation process has the characteristics of raw sewages.
- (h) The solids concentration in the float is a function of

the type and dosage of chemicals used; in the case of alum treatment, the solids concentration of the float are increased in direct relation to the specific alum dose.

- (i) The use of the flocculation chamber offers no advantage in the pilot plant treatment system in terms of improving process efficiency.

RECOMMENDATIONS

The following recommendations are made as result of the present study:

- (1) It is recommended that the dissolved air flotation process be contemplated as a technically feasible alternative in wastewater management systems for the treatment of raw and dilute raw sewages.

- (2) It is recommended that the operating criteria developed for the dissolved air flotation process on the basis of the pilot plant study be used as preliminary operating criteria for the prototype facility pending completion of the prototype demonstration program.

CHAPTER VII

REFERENCES

1. *Technical Objectives for Field Demonstration of Baker Street Outfall Dissolved Air Flotation Facility*, prepared for the City and County of San Francisco by Engineering-Science, Inc., November 1970.
2. *Standard Methods for Examination of Water and Wastewater*, (12th Edition), 1965.
3. *Determination and Removal of Floatable Material From Wastewater*, report by Engineering-Science, Inc. to United States Department of Health, Education, and Welfare, United States Public Health Service, 1965.

APPENDIX A

GLOSSARY

APPENDIX A

GLOSSARY

<u>Specific Symbols</u>	<u>Description</u>	<u>Units</u>
A	Surface area of flotator	area
A/S	Air/solids ratio	weight/weight
f	Efficiency of TSS removal	-
f*	Operations function	-
f'	Optimal operations function	-
f _{OPT}	Maximum efficiency of TSS removal	-
k	First order reaction constant	time ⁻¹
LLR	Liquid loading rate	volume/time-area
P	Pressure	force/area
Q	Volumetric flow rate	volume/time
R _R	Recycle ratio	-
X	Concentration	weight/volume
X ^{AR}	Dissolved air released from recycle flow	weight/volume
X ^S	Influent TSS to flotator	weight/volume

Subscripts

A	Alum
B	Caustic
E	Effluent
F	Float
I	Influent
P	Polymer
R	Recycle
S	Sludge
T	Total (influent plus recycle)

APPENDIX B

MEASUREMENT OF DISSOLVED AIR RELEASE

APPENDIX B

MEASUREMENT OF DISSOLVED AIR RELEASE

INTRODUCTION

The purpose of the dissolved air release measurement is to provide a basis for estimating the volumetric rate of air release from the pressurized recycle flow as this stream enters the flotator. By sampling at a point on the pressured recycle flow line between the air solution tank and the pressure reduction valve in the recycle loop, it is possible to measure the quantity of air released from an aliquot of the recycle flow, and from this, to develop estimates of the rate of air release into the flotator.

PROCEDURE

The procedure entails the controlled diversion of a small stream of pressurized recycle flow into an inverted graduate cylinder as shown in Figure B-1. The air is released into the inverted cylinder from the water carrier, with the result that:

- (1) An air pocket is formed in the graduate cylinder by the released air.
- (2) The water carrier increases over time the total volume of water in the container.

The time of transfer used in the measurement is critical because of the low rate of dissolution of air from the water carrier. In the pilot plant study, a total of 5 to 10 liters of pressurized flow was released at a rate not exceeding 10 l/hr.

The data requirements and a computational protocol for the measurement of the volume of air released per volume of water released (V^{AR}) are demonstrated in Table B-1.

TABLE B-1

DATA LOG FOR MEASUREMENT OF V_{AR}

	Run No.						
	1	2	3	4	5	6	7
<u>Initial Conditions</u> Air Volume (ℓ) Water in Container (ℓ) Water in Graduate Cylinder (ℓ) Total Water Volume (ℓ) <u>Final Conditions</u> Water Volume in Container (ℓ) Top Reading Graduate Cylinder (ℓ) Bottom Reading Graduate Cylinder (ℓ) ΔH (ℓ) Total Water Volume (ℓ) Final Air Volume (ℓ) Water Released (ℓ) V_{AR} (Air Released/Water Released) Time Started Time Stopped Elapsed Time							

COMPUTATIONS

The concentration of dissolved air released from the recycle flow in the pilot plant study was computed as follows:

$$X^{AR} = 7.23 \times 10^6 \left(\frac{407 + H}{T} \right) (V^{AR}) \quad (B-1)$$

where: X^{AR} = dissolved air concentration released from the recycle flow (lb/gal)

H = distance that the air-water interface in the graduate cylinder is below the liquid height in the container (in.)

T = water temperature in container ($^{\circ}K$)

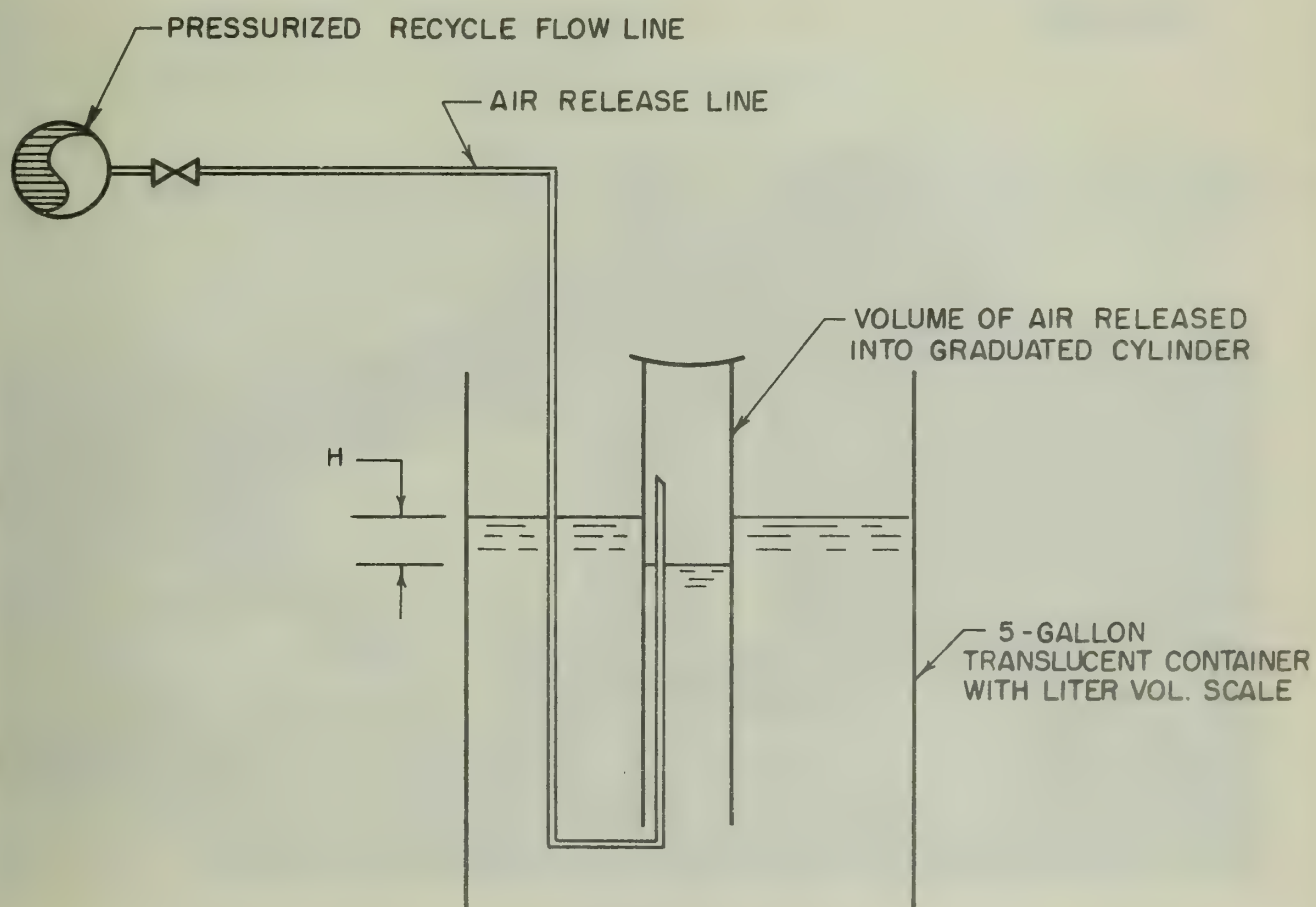
V^{AR} = volume of air released per volume of water released (cc/l)

The dissolved air release rate is computed as follows:

$$Q^{AR} = 12.4 (X^{AR}) (Q_R) \quad (B-2)$$

where: Q^{AR} = dissolved air release rate (SCFM)

Q_R = recycle flow rate (gpm)



MEASUREMENT OF VOLUME OF AIR RELEASED
FROM PRESSURIZED RECYCLE FLOW

APPENDIX D

DISSOLVED AIR FLOTATION

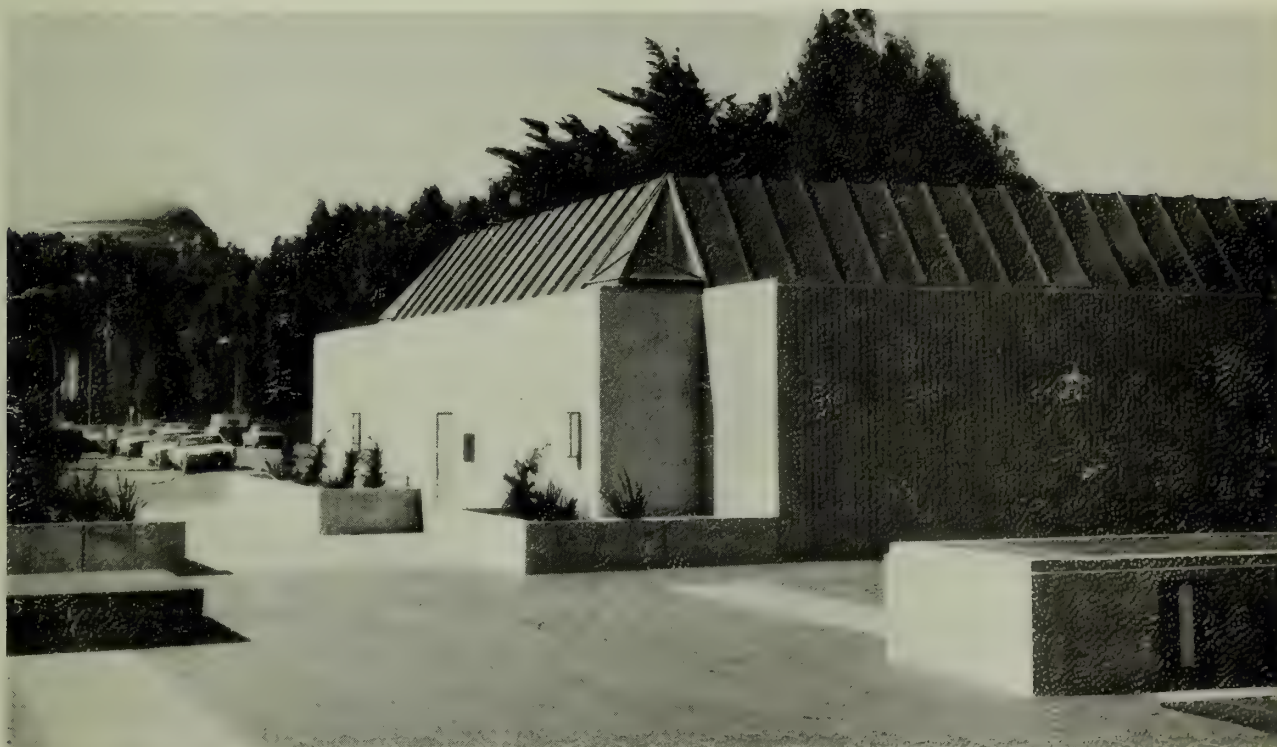
DESIGN FACTORS FOR BAKER STREET
DISSOLVED AIR FLOTATION FACILITY

DOCUMENTS

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JULY 1971

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RESEARCH AND DEVELOPMENT LABORATORY

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DISSOLVED AIR FLOTATION

APPENDIX D

DESIGN FACTORS FOR BAKER STREET
DISSOLVED AIR FLOTATION FACILITY

Part of City and County of San Francisco's
Master Plan Study for Wet Weather Control Program

submitted by

City and County of San Francisco, California

prepared by

Engineering-Science, Inc.
Research and Development Laboratory/Berkeley

for

Environmental Protection Agency
Water Quality Office

July 1971

FOREWORD

This volume constitutes the fourth of seven technical appendices to the Project Report on Treatment of Combined Sewer Overflows by the Dissolved Air Flotation Process. Appendices in this series are:

- A. Phase I - Pre-Construction Studies on Quality and Quantity Relationships of Combined Sewage Flows and Receiving Water Studies at Outer Marina Beach
- B. Technical Objectives for Field Demonstration of Baker Street Dissolved Air Flotation Facility
- C. Treatment of Raw and Dilute Raw Sewage with the Dissolved Air Flotation Process - A Pilot Plant Study
- D. Design Factors for Baker Street Dissolved Air Flotation Facility
- E. Costs for Dissolved Air Flotation Facilities
- F. Characterization of the Receiving Water and Beach Intertidal Zone Environment
- G. Performance Evaluation of Baker Street Facility with Raw Sewage

Appendix D is submitted in partial fulfillment of DPW Order No. 80,480 between the City and County of San Francisco and Engineering-Science, Inc.

This report, prepared in limited edition for utilization in City and County of San Francisco's Master Plan study for wet-weather control, is under review for approval by the Environmental Protection Agency, Water Quality Office.

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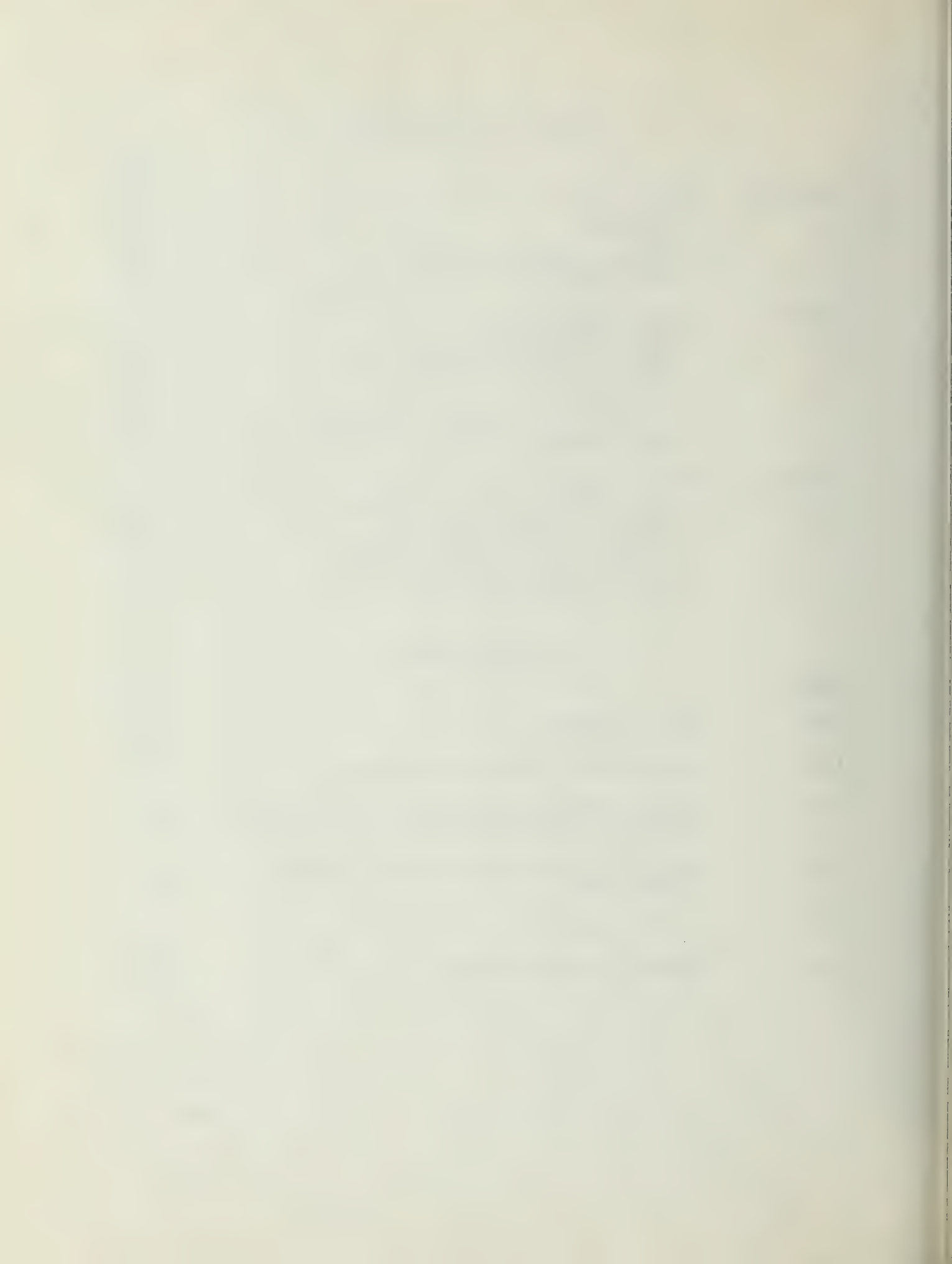
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CHAPTER I

INTRODUCTION

As a part of an overall program of abatement of water pollution from combined sewer overflows, the design, construction, and evaluation of a combined sewer overflow treatment facility at the Baker Street outfall was undertaken by the City and County of San Francisco.

The 24-mgd facility, located southeast of the Golden Gate Bridge between the Presidio and the St. Francis Yacht Club, consists of trash racks, short-term sedimentation for removal of settleable solids, dissolved air flotation for removal of floatable materials, disinfection by chlorination, and a submerged outfall sewer.

Design services in connection with the Baker Street dissolved air flotation facility were furnished by Engineering-Science, Inc. Construction was performed by the S & Q Construction Company.

The objective of this report is to present basic information on the design and construction of the Baker Street dissolved air flotation facility, particularly with respect to approvals, design criteria, construction, construction costs, and operation.

CHAPTER II

PROJECT APPROVALS

The Baker Street dissolved air flotation facility project was received and approved by a number of local, State, and Federal agencies and organizations.

SAN FRANCISCO BAY REGIONAL WATER QUALITY CONTROL BOARD

The San Francisco Bay Regional Water Quality Control Board has supported the project since its conception. In 1967 the Regional Board, by Resolution No. 67-64, requested that the City maintain a schedule for the project such that the Baker Street dissolved air flotation plant would be on-line by 1 June 1970. Later in 1968 the Board, by means of Resolution 68-77, amended its earlier resolution to permit a delay in the facility startup to 1 October 1970. Throughout the course of the planning and design phases, the Regional Board provided support for the project and thereby facilitated the procurement of the approvals from the other various interested and concerned groups.

DEPARTMENT OF CITY PLANNING

The City Planning Commission approved the project on 5 May 1969 subject to conformity with the Master Plan.

DEPARTMENT OF HARBORS AND WATERCRAFTS

The Department of Harbors and Watercrafts approved the project on 20 May 1969. This approval was subject to conformity with the "Harbor Plan, Marina Small Craft Harbor, San Francisco".

ART COMMISSION

On 30 June 1969 the project was approved by the Civic Design, Planning and Art Environment Committee of the San Francisco Art Commission. The project received a commendation for excellence of design as follows:

"This building, disapproved when first submitted in Phase I for the 3 March 69 meeting of the Art Commission has, since then, progressively developed both as an engineering experimental facility and as an architectural work and reveals successful collaborative effort between the several agencies. It culminates in a distinguished architectural building on a site of importance, touching the waters of the Bay, the Presidio on the east, and provides an appropriate westerly terminal element to the Marina shoreline and a recreational feature of the first order.

"The fine proportion of the structure with its copper roof, the elegance of detailing, thoughtful consideration of textures and use of materials all reflect performance too rarely realized in structures for the City. The setting of the building as a feature in the landscape has been studied with relationship to the unique site. The great spacious plant boxes, the broad expanse of slate tile as a finish for terrace and sunning deck, the wide flight of steps descending to the water are features of interest achieved only by thoughtful attention to the whole problem.

"Important, too, is that this excellence is not at the cost of a plant of inferior engineering quality. The facility, part of an extensive engineering research program, is a pilot study to be followed by others if this one proves to be successful."

RECREATION AND PARK COMMISSION

On 22 July 1969 the Recreation and Park Commission, by Resolution No. 8031, approved the project. It was at their request that a paved terrace be provided over the flotation tanks between the control building and the beach which would be open to public access. On final design, public restrooms were included in the control building so that the old convenience station on the east side of Lyon Street might be removed.

UNITED STATES ARMY CORPS OF ENGINEERS

The Corps of Engineers has jurisdiction over all navigable waters,

and in order to construct facilities therein a permit must be obtained. Regulations regarding such permits are contained in Bulletin AGO 20039A, "Permits for Work in Navigable Waters". At the time of the request for and issuance of the permit, the interest was related only to navigation. A request for permit was filed by the City on 10 February 1969 showing horizontal and vertical alignment of a proposed submarine outfall sewer. After a 30-day public notice by the Corps, a permit was issued on 10 April 1969. Subsequently, however, as a result of the final survey of the Bay bottom in the vicinity of the outfall, the alignment was changed and the length was increased. On 2 July 1969, a resubmittal was made and as a result of no objections being raised during another 30-day public notice, the original permit PN 69-28 was approved.

APPROVALS BY OTHER STATE AGENCIES

The Resource Agency of California coordinated responses by various State agencies to the United States Army Corps of Engineers Public Notice PN 69-28 regarding the project. These State agencies included:

Department of Harbors and Watercrafts

Department of Parks and Recreation

State Water Resources Control Board

San Francisco Bay Regional Water Quality Control Board

Department of Fish and Game

Department of Water Resources

Department of Public Health

Division of Highways

Division of Bay Toll Crossings

State Lands Division

The State Lands Division did not object to issuance of a construction permit; however, this did not constitute, nor was it construed as, a waiver of any right, title, or interest in the lands described.

CALIFORNIA WILDLIFE FEDERATION

In response to the Corps of Engineers public notice PN 69-28, the California Wildlife Federation, a statewide conservation organization of sportsmen's councils, replied on 26 March 1969, in part, as follows:

"This proposed project will be most helpful towards improving Bay water quality and will not have any deleterious effect on either the fish and wildlife resources or their habitat which is our main interest in this proposed project."

However, the Federation also requested that consideration be given to extending the outfall into deeper water (which was eventually done as indicated above).

BAY CONSERVATION AND DEVELOPMENT COMMISSION

On 24 February 1969, the City filed an application with the Bay Conservation and Development Commission to dredge material from the Bay, construct an outfall sewer, replace a portion of the material as backfill, and dispose of the remainder at the United State Corps of Engineers' approved dump site south of Alcatraz Island. On 28 February 1969, Permit No. M69-6 was issued under Government Code Section 66032 (d) and the Commission's regulation pertaining to permits for minor repairs or improvements on the grounds that the work would not adversely affect the comprehensive plan prepared by the Commission.

CHAPTER III

PROJECT DESIGN

PROCESS DESIGN

Dissolved Air Flotation

Principle

Flotation is a unit operation for the separation of solid and liquid particles from a liquid phase. Separation is accomplished by introducing dispersed air in the form of fine bubbles into the sewage, or by causing the dissolution of air from a supersaturated recycle stream. The rising bubbles may either adhere to or be trapped in the particle structure and thereby increase the buoyancy of the particles. Particles having a density less than that of the liquid phase can then be separated by flotation.

Methods

Two methods of dissolved air flotation have been successfully used in waste treatment processes. Vacuum flotation is accomplished by first subjecting the waste to a short period of aeration at atmospheric pressure. This step is followed by an application of a vacuum (approximately nine inches of mercury) which induces the precipitation of dissolved air from the saturated solution. The fact that only a limited quantity of air can be precipitated limits the application of vacuum flotation.

The second method (commonly referred to as pressure flotation) involves the solution of air under an elevated pressure followed by release at atmospheric pressure. Equipment components usually employed include a pressurizing pump, air injection equipment, a back-pressure regulating device, and a flotation unit. Air is introduced to a recycle stream usually at the suction end of a centrifugal pump discharging into a retention tank at a pressure ranging from 25 to 70 psig. In passing through the pump, the air is sheared into fine bubbles, thereby facilitating solution in the retention tank. The tank has a retention time of from 30 to 60 seconds and is provided with bleed lines for removing any undissolved air that separates in the unit. From the retention tank the recycle flows through a back-pressure regulating device to the flotation unit.

At the flotation unit, the pressure is reduced to about one atmosphere. Air bubbles released from solution float the suspended particles to the surface where they are removed by mechanical scrapers while heavier solids settle to the bottom and are removed as bottom sludge. Clarified liquid is withdrawn at some depth below the surface out of the zones containing solids.

Applicability

The applicability of dissolved air flotation for waste treatment has been well established. The concept of surface loading rate as the principal efficiency controlling factor has been particularly well documented. The process has seen widespread use in industrial waste treatment in situations where the removal of floatable constituents has been the principal objective. However, in addition to its principal use in industrial waste treatment, dissolved air flotation has also been employed in municipal waste treatment facilities. Results of experiments conducted on dissolved air flotation of raw domestic sewage point to the influence of surface loading rate on suspended solids removal. Research to date on the dissolved air flotation process indicates that it is an excellent method for removing both suspended and floatable materials from municipal and industrial wastes, and that performance equal to or better than sedimentation can be achieved at much greater surface loading rates.

The feasibility of the process for combined sewer overflow treatment has been subsequently established as part of a continuing program to evaluate control methods for combined sewer overflow pollution abatement. Studies have demonstrated that high removals of other constituents can be also anticipated.

Laboratory studies have shown that a recycle ratio in the range of 10 percent will permit substantial reductions not only of greases (hexane extractable materials) but also of gross organic materials (measured as COD). In the laboratory apparatus (described in Appendix B, Technical Objectives for Field Demonstration of Baker Street Dissolved Air Flotation Facility) a sharp break in removal efficiency was characteristically noted after 1-1/2 minutes. This time period corresponded to a surface loading rate of approximately 6,000 gpd/sq ft. Consequently this figure

was selected for the design of the demonstration unit.

The attractiveness of dissolved air flotation is based on two features: (1) effective removal of particulate floatables, oils, and greases; and (2) significantly smaller physical facility requirements than other types of treatment to provide the same or a higher degree of performance. The effective removal of floatables is especially desirable since the floatables are esthetically undesirable. The process has not, however, been utilized under the condition encountered in combined sewer overflow situations, *i.e.*, highly variable flows and quality characteristics.

Chlorination

Previous studies have shown that coliform concentrations in primary sewage treatment plant effluents can be maintained at or below receiving water standards (<10 coliform MPN/ml) if a total residual chlorine concentration of 4 mg/l after 10 minutes is achieved. Using these study results as a basis, chlorine requirements for combined sewer overflows were evaluated (see Appendix B) and found (as anticipated) to be strongly dependent on the organic strength of combined sewer overflows. Because the COD of the overflow seldom exceeds 800 mg/l, a chlorine dosage of 15 mg/l was selected for the treatment facility. This dosage had been shown by laboratory studies to be sufficient to maintain a 4 mg/l residual after 10 minutes in combined sewer overflows having a COD of 800 mg/l. This dosage should insure the discharge of a treated effluent which will meet receiving water bacteriological requirements without dilution.

In order to achieve the desired effects, it is necessary to have sufficient chlorination capacity to treat flows greater than the dissolved air flotation unit design flow. The City's sewerage system has been designed and constructed to accommodate a 5-year storm, which was also selected for the design of the chlorination facilities.

Chlorination is to be carried out on a continuous basis at the headworks of the facility, with the flotation basins serving as chlorine contact tanks.

Design Criteria

Based on the literature, previous research, and studies performed in

conjunction with the Baker Street dissolved air flotation facility, the design parameters shown in Table III-1 were selected.

TABLE III-1
DESIGN PARAMETERS

<u>Hydraulic Capacity</u>	
Inlet System, Bypass System, and Outfall (5-year return interval)	140 mgd
Flotation Plant	24 mgd
<u>Flotation Plant Process Design Parameters</u>	
Surface Loading Rate	6,000 gpd/sq ft
Detention Time	25 min
Recycle	100 to 20% @ 65 psi
Available Air	68 SCFM @ 65 psi
<u>Chemical Addition for Flotation Aids</u>	
Soda Ash Feeding Capacity, 50% trade solution	15 to 150 mg/l @ 12 mgd
Alum Feeding Capacity, 36° Be	30 to 300 mg/l @ 12 mgd
Polyelectrolyte Feeding Capacity, 1% solution	0.1 to 10 mg/l @ 24 mgd
<u>Chemical Addition for Disinfection</u>	
Sodium Hypochlorite, 15 % trade solution	15 mg/l @ 24 mgd
<u>Sludge Pumping Capacity</u>	550 gpm

Equipment Selection

After establishing the design parameters various equipment manufacturers were contacted and consulted. The major items of equipment specified were based on the applicability and quality of available equipment. Table III-2 lists equipment and materials supplied.

HYDRAULIC DESIGN

Tidal Analysis

Estimates of the extreme high and low tides which may occur at the

TABLE III-2

MAJOR ITEMS OF MATERIAL AND EQUIPMENT

Material or Equipment	Manufacturer or Supplier
Bar Screens and Conveyor	Rex Chainbelt, Inc.
Sludge Collectors, Skim Pipes, and Screw Conveyors	Rex Chainbelt, Inc.
Pressurization Systems	Eimco Corp.
Sluice Gates	Armco Steel Corp.
Hydraulic (Oil) Power and Controls System	Garrett Fluid Components
Fiberglass Chemical Storage Tanks	Fiberglass Structures
Chemical Feed Pumps	BIF
Air Lift Pumps	Chicago Pump Co.
Sludge Pump	Wemco
Sump and Plant Water Pumps	Pacific Pumping Company
Electrical Panels and Switchgear	Square D
Instrumentation and Controls	Fischer & Porter Co.
Ventilating	Carnes Corp. and McQuary, Inc.
Outfall Sewer Pipe	American Pipe and Construction
Ready Mix Concrete	Bode Gravel
Reinforcing Steel	Judson Steel Co.
Structural Steel and Miscellaneous Iron	Michel & Pheffer

Site of the proposed facility were necessary in order to (1) estimate probabilities that tides will be too high to allow discharge of treated effluent into the Bay, and (2) set high and low groundwater elevations to establish buoyancy parameters for buried elements of the plant.

The closest tide station to the site is the Presidio Tide Station, San Francisco, California, where tide records have been maintained since 1897.

Datum Analysis

Chart Datum, Mean Lower Low Water (MLLW), elevation 0.00, was 5.61 ft above Tide Staff elevation 0.00 from 1897 to 1960, when it was revised to 5.54 ft. Tide records are elevations above Tide Staff Datum 0.00. Tide Predictions are related to Chart Datum 0.00 and are taken as 5.54 ft above Tide Staff Datum.

Chart Datum 0.00 is 11.68 ft below the City of San Francisco Datum elevation 0.00. All elevations are relative to the City Datum 0.00 and are, consequently, obtained by subtracting $5.54 + 11.68 = 17.22$ ft from Tide Staff elevations or 11.68 ft from Tide Prediction elevations.

Extreme High Tide

The monthly extreme high tides of the six wet-weather months of October through March for the 70-year period from October 1897 through March 1967 were analyzed for probability of occurrence, and the probability that the extreme monthly high tide will be equaled or exceeded was plotted. A conservative hydraulic analysis of the required head for discharge of a total plant flow of 37 cfs (18.5 cfs per flotator) indicated that sea water may stand in the launder trough to an elevation of -3.65 ft (0.65 ft below bottom of weir notch and 0.95 ft below flotation liquid level). The probability that tide elevations will exceed -3.65 ft is less than two percent. Therefore, extreme high tides should not adversely affect the hydraulic discharge from the plant.

Extreme Low Tide

A comparison between daily extreme low tides of record and predicted tides was made for the 183-day period from 1 April to 30 September 1967. Tides of record were consistently higher than predicted tides (maximum, 0.8 ft; minimum, -0.2 ft; average, 0.16 ft; mean, 0.1 ft). A detailed

analysis of the effects of wind and barometric pressure was beyond the scope of the design; however, a conservative analysis was made of the extreme monthly low predicted tides for the 132-month period of 1959 through 1969 and the probability that there will be a tide lower than -14.0 ft is less than 0.01 percent.

Buoyancy

Design groundwater elevations assumed for buoyancy calculations were -3.40 ft for high water and -14.0 ft for low water.

COMBINED SEWAGE

Domestic sewage from the 167-acre Baker Street drainage area is collected and transported to the Baker Street diversion, at which point it is intercepted and transport through the Marina Pumping Station to the North Point Sewage Treatment Plant. The diversion is designed to bypass combined wet-weather flow to the Baker Street outfall. Available data were used and interpreted to evaluate anticipated quantities of combined wet-weather flow that would be treated at the Baker Street dissolved air flotation facility.

Overflow at Baker Street Diversion

The Baker Street diversion was designed by the City to overflow with rainfall of intensity greater than 0.02 in./hr. At least 12 of the average 38 rainstorms per year would exceed 0.02 in./hr and would overflow to the flotation facility.

Treated and Bypassed Flow

For the 24-mgd design capacity of the dissolved air flotation facility, and a season of normal rainfall, a normal seasonal total of six inches of rainfall (or 17.7 million gallons at a runoff coefficient of 0.65) would be treated at the facility and one inch of rainfall (3 million gallons) would be bypassed around the plant without treatment.

In a normal season the design capacity of the facility (24 mgd) will be exceeded for only about two hours each year, and 12 mgd will be exceeded for about 20 hours.

A total of 3.06 inches of rainfall or more would bypass the facility

with a return frequency of five years and the minimum facility bypass in 62 years would be 4.35 inches of rainfall. These rainfall levels are equivalent to nine million gallons of annual bypass at a 5-year frequency and a maximum annual bypass of 12.6 million gallons, respectively.

STRUCTURAL DESIGN

Soils Survey

Prior to commencing structural design, a soils survey was conducted to (1) investigate the subsurface conditions at the site; (2) evaluate the general strengths, compressibilities, and permeabilities of the subsoils; (3) locate the groundwater table elevation; and (4) make recommendations regarding foundation design, lateral loads, and excavation and dewatering during construction. The foundation loadings imposed by the planned structure were less than the weight of soil removed in the scheduled excavation. Consequently, additional resistance or dead load was needed to overcome uplift pressures due to the high groundwater level. Brewer and Associates, Consulting Foundation Engineers of San Francisco were engaged to perform the required soils survey.

Subsurface conditions at the site were explored by the drilling of five land test borings extending to depths of from 70 to 115 ft below the existing ground surface. The drilling of the land borings was accomplished using truck-mounted rotary-wash drilling equipment.

To evaluate the general strengths and compressibilities of the subsoils a series of shear tests and consolidation tests were performed on selected core samples extracted from the test borings. In addition, permeability and sieve analyses were performed on representative samples of the upper sands, and one test was conducted on the underlying silty clay mixed with sand for comparative purposes.

In general, the test holes disclosed the site to be blanketed by some 40 ft of medium dense sand with gravel and rock fragments. These sands varied appreciably in gradation--from fine to medium to coarse. Underlying the sands, weak silty clays mixed with fine to medium sand were encountered and found to extend to the full depth of the test borings. These clayed marine deposits, containing broken shells, have a relatively

low density, but a higher density due to the sand content than the so-called "bay mud" deposits. Reference to geological source data indicated that the area has been reclaimed from the margins of San Francisco Bay. Old maps show the general area to have been a swamp and water area in the past. Reportedly this area was reclaimed in about 1912 by dredging operations for the Panama Pacific International Exposition. Accordingly, the upper sands overlying the clayed marine deposits were considered to be man-made fills. While considerable debris and rubble is present in the more recent fills along the Bay edge of the adjoining Presidio property, only minor insignificant amount of debris was uncovered in the test drillings.

The upper sand fills have reasonably good strengths and relatively low compressibilities. However, because of the granular character of this material and lack of fines, the fills are highly permeable. Coefficients of permeability as great as $7,100 \times 10^{-4}$ cm/sec are indicated by laboratory test for the sand fill. The permeability of the underlying clayed marine deposits (the silty clay mixed with sand) is extremely low, being 2,000 to 3,000 times less permeable than the sand fill.

Water was encountered in all of the test borings at rather shallow depths. Brief observations indicated that the groundwater table varied with tidal change, as would be expected in view of the proximity of San Francisco Bay to the plant site.

With regard to the support, it was concluded that the sand fills were fully capable of supporting the proposed structure. In fact, the planned loadings did not exceed the effective weight of overburden removed in the excavation. The probable total settlement, due to recompression of the soils after unloading by the basement soil removal and dewatering, was estimated not to exceed 1-1/2 in. In addition to the indicated settlement due to recompression of the subsoils, some small areal settlement would doubtlessly remain under the superimposed weight of the areal fills. This should pose no serious problem because such areal settlement would effect the entire project site. Any future filling would, of course, again accelerate and increase the areal settlements.

As the structure was planned to be depressed well below groundwater level, the mat foundation had to be capable of resisting the hydrostatic

uplift pressures. In this connection, consideration was given to the possible use of uplift piling in lieu of increasing the weight of the foundation mat. Use of the uplift piling was subsequently eliminated in favor of increasing mat weight due to (1) difficulties in properly installing the piling through the sand fills, (2) the questionable uplift capacities that might be safely developed, and (3) the cost factor.

With regard to lateral pressures, it was decided that the proposed structure be designed to resist earth and full hydrostatic water pressures. Analyses indicated that the basement walls should be designed on the basis of an equivalent "fluid" pressure of 80 psf.

Prior to construction of the foundation mat, it was determined that the exposed subgrade be compacted to assure against the presence of loose or disturbed soils resulting from the making and working of the basement excavation. Further, as discussed below, proper dewatering of the site was indicated to guard against "blow-out" of the bottom of the excavation and/or the development of a "quick" condition. While actual compaction tests were not performed on the sand fill, it was the opinion of the soils consultant that these sands could be reused in the backfilling operations. Ponding of these sand backfills, together with some small vibratory effort, was anticipated to result in satisfactory compaction.

Such a major excavation requires bulkheading and extensive dewatering. It was assumed that interlocking steel sheet piling would be employed and subsequently removed at the end of construction. Prior to the opening of the excavation, it was determined that the project area be adequately dewatered to assure against severe disturbance and "blow-out" of the bottom of the excavation. It was further required that the water level be maintained at a depth of at least five feet below the bottom of the excavation at all times and that periodic water levels be observed during the grading and construction work. In this connection, use was made of three existing piezometer pipes as observation holes. The dewatering of the site, whether by means of wells, well-points, or a combination thereof was not fully investigated by the soils engineer and, consequently, this option was left to the contractor. However, it was required that provisions be made for the installation of an automatic alarm system should pump failure occur in order that such could be promptly corrected.

Liveload Conditions

The various liveload conditions for the structural design were as follows:

(1) Slab on top of flotators - 100 psf.

(2) Transformer slab - 200 psf.

(3) Equivalent fluid pressure on walls submerged in ground 80 psf per foot of depth.

(4) Control building loading:

(a) Roof - 30 psf.

(b) Floor - 100 psf.

(c) Future chlorine storage room - 150 psf.

(d) Hopper suspended from roof system - 10,000 pounds.

(e) Monorail suspended from roof structure - 2 ton capacity.

(5) Areas where trucks will be driving received H₂O truck loadings. This includes the portion in the control building and also the slab on top of the flotator units.

Structural Systems

The flotation tanks were designed for concrete floors, walls, and roof slab, with tanks buried in the ground so that the roof slab is approximately at grade level. Because of the high groundwater table, the tanks were designed to resist buoyancy when empty. This design constraint predicated the use of the large foundation slab under the tanks. The walls were designed for equivalent fluid pressure, including the pressure of the water when empty. The inlet and outlet structures were designed for the same conditions as the flotation tanks.

The control building was designed with a steel deck roof, steel purlins, and structural steel trusses that clear span the building. These also provide support for the equipment attached to the roof structure.

The floor framing consisted of reinforcing concrete beams and slabs. Exterior walls were designed of reinforced concrete and loading conditions

were considered for all equipment located on the floors and at the inlet structures. The 1969 edition of the City and County of San Francisco Building Code was used on all structural design work.

ELECTRICAL DESIGN

Facility Power and Control Systems

The Baker Street dissolved air flotation facility is served by the Pacific Gas and Electric Company via an underground 12-kv primary source which was extended to the plant. A 12-kv, 480/277-v, 3-phase, 4-wire, pad-mounted transformer was located adjacent to the northwest corner of the control building for transformation to the utilization voltage.

A 480-v, 3-phase switchboard and motor control center was designed to face the main control console in the control room. The control center provides the power, lighting, and control for the entire facility.

All the process equipment including the ventilation system were designed for either manual operation or automatic control through the use of mode selector switches and the associated automatic instrumentation located in the control console.

Equipment alarm failures were provided through the use of failure alarm relays and contacts wired into each equipment control scheme to provide the failure signal to the local alarm annunciator in the control console and to provide for remote annunciation (as described below) in the telemetering system.

Lighting

A 480-120/208-v step-down transformer and branch circuit lighting panel was provided for operating voltages for the lighting system, convenience receptacles, and miscellaneous 120-v loads.

Illumination levels for the general equipment areas was designed for 30 footcandles utilizing incandescent lighting fixtures. Approximately 100 footcandles of illumination was provided in the control room through the use of fluorescent fixtures utilizing 800 ma high output tubes.

Decorative, low-mounted, nonglare type lighting fixtures were

specified for walls housing equipment above the flotation tanks and pipe gallery to complement the park-like surroundings adjoining the plant.

Emergency System

A 25 kw, 480-v, 3-phase emergency generator set and automatic transfer switch was provided to maintain the required ventilation system in operation and to provide emergency lighting in the event of a power failure.

An isolated, normal-emergency, 480-v, 3-phase bus in the main switchboard lineup containing ventilation control equipment, transfer switch, and a 120/240-v, single-phase transformer and panel for lighting was provided for this system.

Telemetering System

A telemetering system utilizing a leased telephone line from Pacific Telephone and Telegraph Company was provided to monitor plant operations and failures at the City's Army Street maintenance yard.

The remote annunciator was designed to receive signals via the telephone line to indicate (1) that both the east and the west flotation tank equipment are in operation; (2) a high level condition at Baker Street; (3) sodium hypochloride tank at low level; (4) a bypass gate failure; and (5) a plant general equipment failure.

A 2-pen strip chart recorder was also provided to continuously record the flow in both the east and the west flotation units.

ARCHITECTURAL DESIGN

The facility is located on a prominent site adjacent to Saint Francis Yacht Club, Public Park, and Presidio overlooking San Francisco Bay and the Golden Gate, and San Francisco Art Commission approval was required for the project. Drawings prepared by John Bartlett and Associates, AIA, of Alhambra, California, were reviewed on four occasions by the Civic Design, Planning and Art Enrichment Committee. As indicated previously, the Committee commended the project for its excellence. The landscaping was reviewed and approved by the Parks and Recreation Department.

Architecturally the facility consists of a rectangular concrete structure of approximately 3,200 square feet for equipment with street level public toilets and a public plaza of approximately 10,000 square feet. A maximum height of approximately 18 feet was required for the equipment within the structure. To reduce the visual height the concrete walls were limited in height to 12 feet with the addition of a "Mansard" type metal roof frame set back above the concrete walls to gain the additional six feet in interior height over a portion of the structure. The roof frame was sheathed in copper with glass corner skylights to provide light into the equipment area. Exterior walls were designed with a textured, sand-blasted finish in a natural gray. The area over the tanks was designed as a public plaza and the required surface venting and equipment for the tanks were concealed in planters. The level of slate-surfaced plaza is approximately two feet above grade with steps and walks leading to the plaza of exposed aggregate concrete finish. The visual space of the plaza and facility is defined by raised planters, screen walls, and benches. The area is illuminated for night use.

OUTFALL DESIGN

Oceanography

The preconstruction evaluation program included extensive receiving water monitoring studies, which consisted of collection and analyses of receiving water and benthos, wind and tidal observation, and current measurements. These studies, conducted for both wet- and dry-weather conditions, were extensive and are documented in Appendix A, Preconstruction Studies on Quality and Quantity Relationships of Combined Sewage Flows and Receiving Water Studies At Outer Marina Beach. Currents of 2.5 knots were observed at a distance of 250 feet from shore and significant sand shifting in the area of the outfall terminus was observed.

Outfall System

As a result of the above two observations, the particular outfall system was chosen. A trench system with gravel bedding and ballast with a concrete cap encased between steel sheet piles was selected. To provide for an extra factor of safety, a current velocity of five knots was calculated as lateral pressure. The pipe was "day lighted" at a minimum

depth so as to project up sufficiently from the Bay bottom to prevent silting and to remain sufficiently below mean lower low water so as not to create a hazard to navigation.

Alignment

The City's survey staff performed the hydrologic survey of the Bay bottom in the vicinity of the outfall. Based on the results of the survey, the outfall was realigned and lengthened from the preliminary design to meet the required depth constraints imposed by navigation and silting. The final design resulted in a 290-ft long, 108-in. diameter reinforced concrete pipe terminating in approximately 30 ft of water. The United States Coast Guard required that a light be placed on a pile at the outfall terminus to serve as an aid to navigation.

Soils Survey

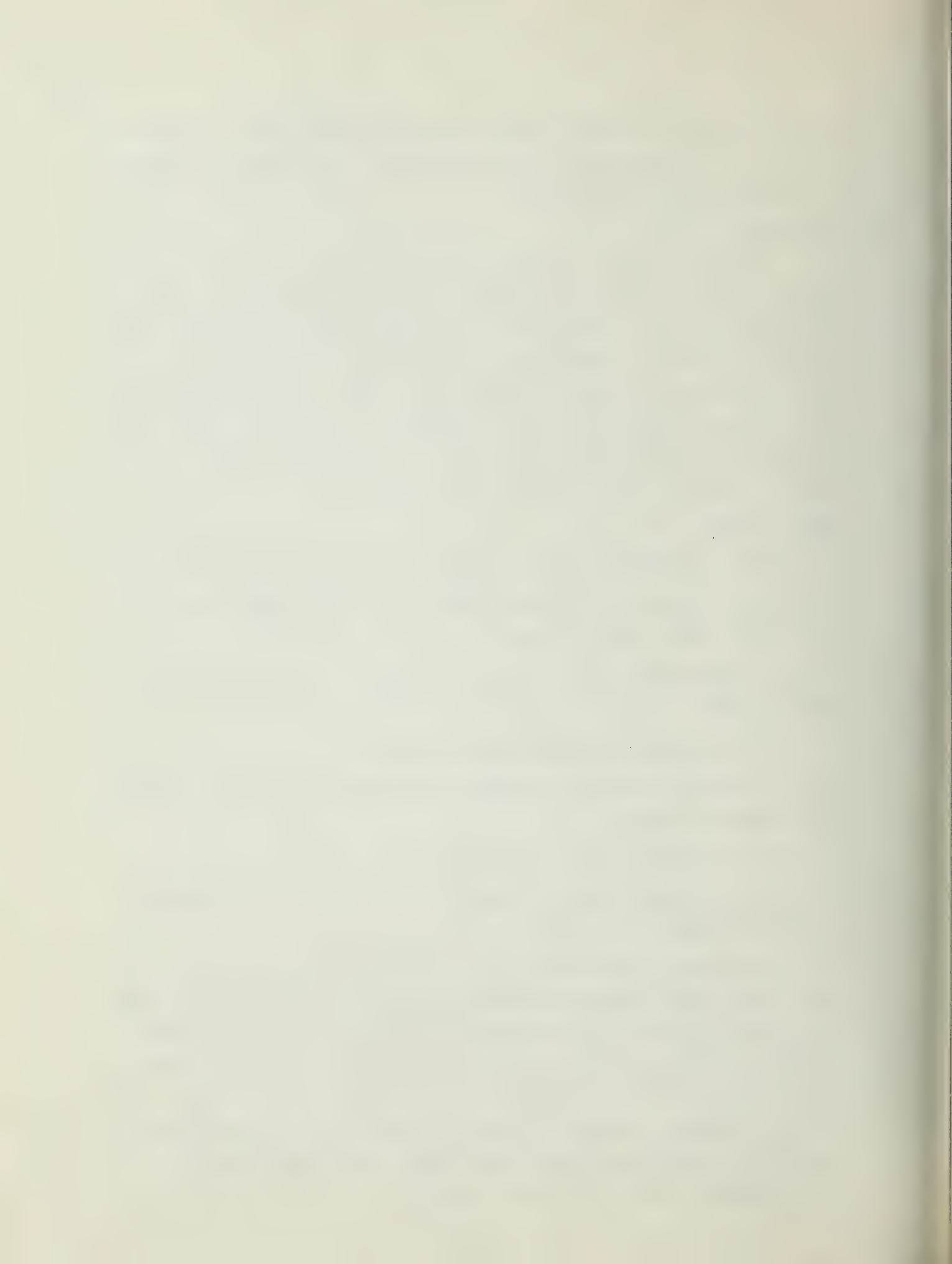
Prior to commencing final design a soils survey was conducted to:

- (1) Indicate rock or other material which would inhibit driving of single piles or sheet-piling.
- (2) Recommend, for single piles, values for downward loads and uplift loads.
- (3) Recommend the type (material) of pile.
- (4) Require sheet-piling penetration to given base fixity, together with depth of fixity.
- (5) Estimate expected settlement.

This work was performed by Harding, Miller, Lawson and Associates of San Francisco.

The site was investigated by drilling two borings to depths of 62 and 63 feet using a barge-mounted wash drill rig. The soils were logged by a field engineer and core samples and bag samples for visual classification and testing in the laboratory were obtained. The soils were classified in accordance with Unified Soil Classification System.

The laboratory testing program consisted of moisture content-dry density determinations, classification tests, and strength tests (consolidated-drained direct shear tests).



In general, the south end of the site was found to be underlain by up to 20 feet of loose sand fill containing some gravel and debris, especially in the lower portions. Beneath the fill, and in the north end of the site, loose silty sand and sandy silt was encountered to the depths explored.

To provide base fixity, sheet piles were designed to be driven to a depth below the dredge level (below lowest adjacent grade during or after construction) of at least 45 percent of their total length. The computed required section moduli of steel sheet piles for two conditions were as follows:

Condition 1 (Station 0+00 to 2+00) - Sheet piles retaining sand (mostly old fill) during construction; maximum unsupported height of 15 feet.

Condition 2 (Station 2+00 to 2+90) - Sheet piles retaining bedding material and ballast; maximum unsupported length of 22 feet.

The computed section moduli and alternate pile types which would be suitable for each condition are presented in the following table (pile types of other manufacturers were also considered suitable):

	<u>Section Modulus</u>	<u>Alternate 1</u>	<u>Alternate 2</u>
Condition 1	8 in. ³	Bethlehem DP-2	U.S.S. M116
Condition 2	22 in. ³	Bethlehem ZP-27	U.S.S. MZ-27

The above selections included an allowance of at least 1/16-in. for corrosion. Section moduli were computed assuming no surcharge loading behind the sheet piles (such as heavy construction equipment or stock-piled materials). The section moduli were based on movements induced in the piles by lateral soil pressures. The ability of the piles to withstand stresses induced by driving were required to be checked by the contractor.

Because the sheet piles would be driven primarily in loose sand, blow counts, obtained while sampling during the field exploration, (converted to "standard penetration test" blow counts) were included on the boring logs to aid the contractor in evaluating driving resistance.

The north end of the outfall supported above existing grade was predicted to settle as the underlying silty sand consolidated under the new load. It was estimated that the extreme north end of the outfall (Station 2+90) would settle approximately six inches. Because the portion of the outfall constructed below grade (Station 0+00 to 1+90) was not expected to settle appreciably, differential settlement for the last 100 feet was predicted to be about six inches. It was estimated that about 70 percent of this settlement would take place in the first year after construction.

Structural Pipe Design

The structural design parameters for the concrete pipe were as follows:

- (1) Trench condition.
- (2) Class C Bedding - Load Factor = 1.5.
- (3) Maximum cover of 10 feet.
- (4) Internal pressure - insignificant.
- (5) Wheel load (due to vehicle on beach) - 20 k.

As part of the required submittals to the engineer for review prior to construction, the pipe manufacturer was required to submit final pipe design calculations for review. Pipe joints were specified as double neoprene gasketed. Between the gaskets a monel pressurization tube was designed to be cast into the pipe so that during the laying operation the integrity of each joint could be tested by applying pressure to the cavity between the two gaskets. A special terminus section was cast at the end of the outfall. This terminus was designed to allow for the projected settlement (as noted above), and to facilitate future extension of the outfall should it be subsequently required.

SPECIFICATIONS

The specifications may be categorized under two major headings: (1) Standard Specifications, and (2) Special Provisions. The Standard Specifications were those of the City of San Francisco, Department of Public Works, Bureau of Engineering, dated 1965. The Special Provisions

of the specifications were numbered Specification No. 23,060 and included not only the written Special Provisions but the contract drawings as well. The Special Provisions included certain revisions to the General Provisions of the Standard Specifications as well as the main body of the Technical Specifications. Reference is made to these documents for specific items of information. However, two unique interrelated items of the General Provisions and the bid form are of note. Section 3 of the Special Provisions entitled *Times Allowed for Placing Plant in Satisfactory Operation and for Completion of All the Work* specified three propositions--A, B, and C--for the duration of (1) placing the plant in satisfactory operation, and (2) completion of all the work. These times are as listed in Table III-4. Also included in Section 3 was the provision notifying the contractor that night work and week-end work would be permitted with the exception of work which would cause any objectionable noise to the residents in the vicinity. Section 4 of the Special Provisions entitled *Liquidated Damages for Delay in Placing Plant in Satisfactory Operation and for Delay in Completion of All the Work* stipulated a liquidated damage clause for failure to complete the work. Liquidated damages for delay in placing the plant in satisfactory operation were assessed at \$700 per calendar day, and liquidated damages for delay in completion of all the work were assessed at \$100 per calendar day. Furthermore, the liquidated damages were specified to run concurrently. The following clause was included in the specifications:

"Satisfactory operation shall be considered to be as satisfactorily demonstrated actual operation of the basic functional process facilities which receive, process, and dispose of the combined storm and sanitary influent flow. It shall be further mutually understood and agreed that any required painting, etc. of tanks or equipment which will be in contact with the sewage or any other work which would be impracticable to accomplish after the plant is in operation shall be accomplished before the plant is put into operation."

The amount of liquidated damages to be assessed for failure to place the plant in operation or to complete the project was given careful consideration at a monthly meeting of the Project Advisory Board held in the summer of 1969. The Project Advisory Board consisted of the chief

TABLE III-3

TIMES ALLOWED FOR PLACING PLANT IN SATISFACTORY
OPERATION AND FOR COMPLETION OF ALL THE WORK

<u>Times Allowed for Placing Plant in Satisfactory Operation</u>	
Proposition A	240 days
Proposition B	300 days
Proposition C	450 days
<u>Times Allowed for Completion of All the Work</u>	
Proposition A	360 days
Proposition B	420 days
Proposition C	570 days

NOTE: All times referred to above were in consecutive calendar days measured beginning with and including the official date for the commencement of the work.

or his appointed alternate of the following agencies: Water Resources Control Board; San Francisco Bay Regional Water Quality Control Board, City and County of San Francisco; State of California Department of Public Health, Bureau of Sanitary Engineering; State of California Department of Fish and Game; and Engineering-Science, Inc. Schedules for solutions to the combined sewage discharge problem as proposed by the resolutions of the Regional Water Quality Control Board (as discussed in Chapter II) were reviewed and discussed. Also discussed was the recently enacted Porter-Cologne Water Quality Control Act of November 1969 which provided for a fine of \$6,000 per calendar day for failure to comply with the San Francisco Bay Regional Water Quality Control Board Resolution 68-77 requiring startup by 1 October 1970.

Based on Sections 3 and 4 as described above, bidders were required to bid on all three propositions. In the notice to bidders the following directions were provided:

"The Director reserves the right, if an award is made, to award the contract on the basis of either Proposition "A", "B", or "C", as appears to him to be best in the City's interests, and in order to comply, if economically feasible, with certain time limits set forth by the Regional Water Quality Control Board."

As a result, the project was bid under all three propositions and the list of bids is discussed in Chapter IV.

CHAPTER IV

PROJECT COST

ESTIMATES

As required by the agreement between Engineering-Science, Inc. and the City, an updated preliminary construction cost estimate was provided in each monthly progress report during the design period. With the submission of final plans and specifications, a final construction cost estimate was also provided. This estimate was made in significant detail by taking off quantities from the final drawings and utilizing current unit costs. Equipment manufacturers submitted prices for equipment including an estimate of the man hours for installation. The cost for site dewatering was established by estimating the rental on sheet piling, well points pumps, and headers. Every pipe, valve, and fitting was itemized and the cost of installation was estimated using current labor and material prices. The installation man hours were estimated utilizing the "Manual of Commercial and Industrial Construction Estimating and Engineering Standards".

A summary of the final cost estimate prepared by Engineering-Science, Inc. is presented in Table IV-1.

BIDS

The formal announcement inviting bids was advertised on 19 December 1969. During the bidding period two addenda were made part of the contract documents. The bids were opened on 7 January 1970 and a listing of the bids is presented in Table IV-2.

On 28 January 1970, the contract was awarded on the basis of Proposition A to S & Q Construction Company of South San Francisco for the low bid of \$2,062,510.

PROGRESS PAYMENT BREAKDOWN

For purposes of establishing the basis for percentage completion,

TABLE IV-1

ENGINEER'S FINAL CONSTRUCTION COST
ESTIMATE SUMMARY SHEET

I	Site Dewatering	\$ 168,000
II	Earthwork	63,000
III	Reinforced Concrete	395,000
IV	Structural and Miscellaneous Steel	30,000
V	Ocean Outfall	397,000
VI	Plant Influent	115,000
VII	Plant Bypass	38,000
VIII	Force Main	32,000
IX	Pipe, Valves, and Fittings	152,000
X	Mechanical Equipment	270,000
XI	Instrumentation and Controls	130,000
XII	Electrical Work	79,000
XIII	Ventilation	14,000
XIV	Architectural Work	73,000
XV	Painting	6,000
XVI	Landscaping	18,000
XVII	Demolition	16,000
XVIII	Relocate AWSS	12,000
	Total Estimated Construction Cost	<u>\$ 2,008,000</u>



TABLE IV-2
LIST OF BIDDERS

Bidder	Bid Proposition		
	A	B	C
S & Q	2,062,510	2,002,510	2,001,510
Houben Ind.	-	2,082,209	2,092,209
Fryethy	2,102,000	2,060,000	1,950,000
Masman Construction	2,252,160	2,194,060	2,152,760
Northwest	2,271,000	2,223,000	2,160,000
Mitchell	2,308,300	2,239,300	2,178,300
Healy Tibbitts	2,424,850	2,372,530	2,249,250
Williams & Burrows	2,528,000	2,428,000	2,438,000
Olsen-Covington	2,542,711	2,482,711	2,482,711
Rothchilds & Raffin	2,587,000	2,437,000	2,292,000

and to determine the amount of the monthly progress payment, the contractor was required to prepare a Progress Payment Breakdown, shown in Table IV-3.

CHANGE ORDERS

Throughout the course of construction, a number of change orders were required. (The nature of these are described in detail in Chapter V.) The net increase in cost of the project due to these change orders was \$31,145. These changes brought the final completed construction cost to \$2,093,655, which is less than two percent increase in the original contract price.

TABLE IV-3
PROGRESS PAYMENT BREAKDOWN

Description	Quantity	Unit	Total
Mobilization & Bond	L/S		\$ 50,000.00
Civil			
Cofferdam-Main			
Install	L/S		106,000.00
Remove	L/S		22,000.00
Excavation-Main	13,600 cy	6.50	88,400.00
Dewatering-Main	L/S		22,000.00
Backfill-Main	2,500 cy	3.00	7,500.00
Concrete-Main	5,046 cy	132.00	666,072.00
Re Steel	L/S		42,560.00
Outfall	L/S		300,000.00
Influent Sewer			
Excavation	3,370 cy	5.00	16,850.00
Concrete	424 cy	142.00	60,208.00
Backfill	2,200 cy	3.00	6,600.00
Bypass Sewer	126 cy	140.00	17,640.00
Paving	L/S		2,400.00
Demolish Outfall	L/S		17,600.00
Landscape	L/S		6,600.00
	Subtotal		\$1,432,430.00
Architectural			
Sheet Metal & Copper Roof	L/S		7,700.00
Roofing	L/S		1,850.00
Doors, Frames & Fin. Hardware	L/S		2,000.00
Glass & Glazing	L/S		1,000.00
Painting	L/S		20,700.00
Slate Masonry	L/S		18,800.00
Miscellaneous Carpentry	L/S		2,200.00
Misc. Iron & Stru. Stl.	L/S		55,600.00
	Subtotal		\$ 109,850.00

TABLE IV-3 (Cont'd)
PROGRESS PAYMENT BREAKDOWN

Description	Quantity	Unit	Total
Mechanical Work			
Embedded & Large Pipe	L/S		\$ 48,600.00
Small Piping	L/S		28,450.00
Major Equipment			
Bar Screen & Conveyor	L/S		47,600.00
Sludge Collector & Conveyor	L/S		64,200.00
Gates, Thimbles & Hydraulic Systems	L/S		63,500.00
Pressurization System	L/S		34,000.00
Pumps & Chemical Feed Systems	L/S		20,400.00
Instrumentation			75,000.00
Force Main	2,780 LF	16.00	44,480.00
Water Service & Aux. Water Service System	L/S		5,000.00
Heating & Ventilation	L/S		8,000.00
	Subtotal		\$ 439,230.00
Electrical Work	L/S		78,000.00
Cleanup & Demobilize			3,000.00
		TOTAL	\$2,062,510.00

CHAPTER V

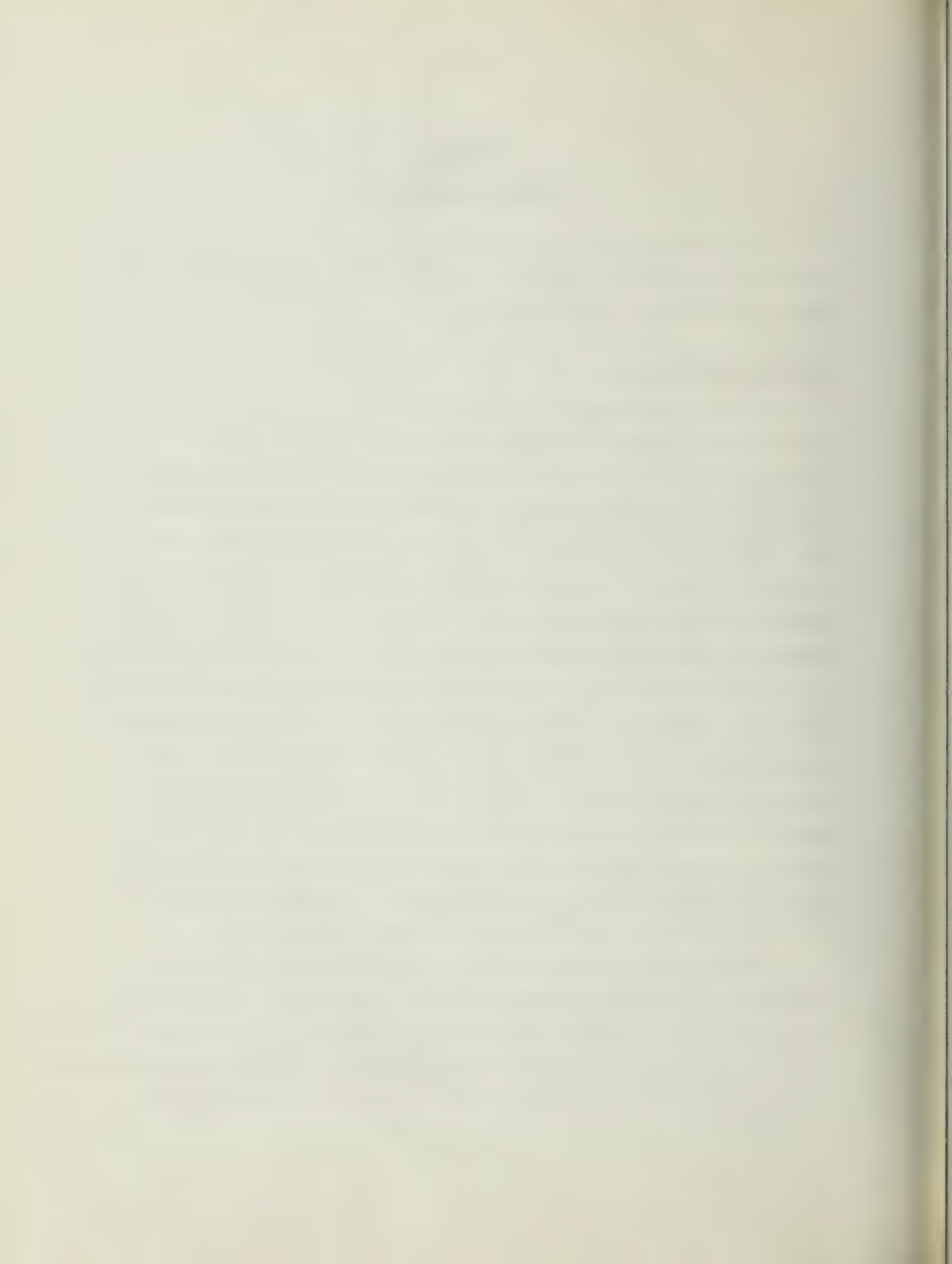
PROJECT CONSTRUCTION

The contract was awarded under Proposition A which provided for the least period of time to complete construction. The initial starting date for construction was 9 February 1970.

CONSTRUCTION SCHEDULING

As a part of maintaining the project on schedule, the contractor was required to prepare a critical path method diagram of the project from start to finish. Included along the critical path were such items as the installation of the underground main power conduit and temporary power system, installation of the dewatering wells and pump system, excavation of the cofferdam, placement of the base slab concrete, placement of the below-grade concrete walls, placement of the support slab over the flotation tanks, installation of the below-grade equipment, including the pumps and pressurization system, instrumentation, and facility checkout. In order to meet the schedule the contractor began immediately ordering equipment and materials for the job. He also began final design of the cofferdam and dewatering system. As soon as the award was made, the contractor negotiated his subcontracts and transferred to his major equipment suppliers the obligation for liquidated damages to serve as an incentive to the equipment suppliers to deliver equipment on time. Weekly meetings were held with the City's resident engineer and the contractor's superintendent. These meetings served to keep the project on schedule and determine any field conflicts.

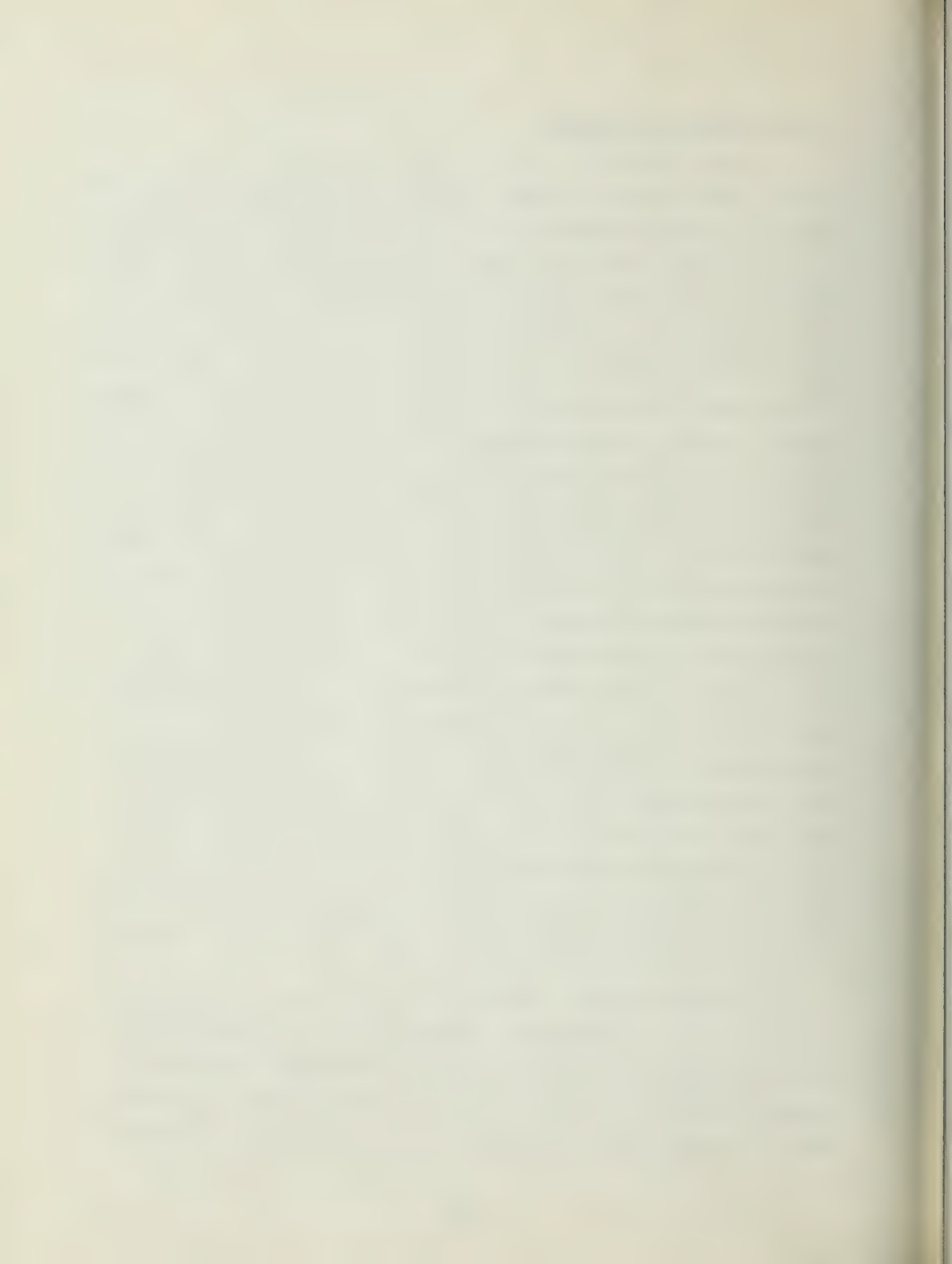
To avoid delay to the contractor, a 2-week maximum lag period was established for the total checking period for the numerous required shop drawing submittals. Despite the complexity, this schedule was adhered to and facilitated the timely ordering and fabrication of equipment and materials. Throughout the construction phase, the project remained substantially on schedule.



SPECIAL CONSTRUCTION METHODS

In order to construct the facility in the immediate proximity of the Bay and under severe groundwater conditions, an extensive cofferdam and dewatering system was designed, installed, and maintained by the contractor utilizing steel sheet piling. Steel sheet sections were chosen in conformance with the recommendations by the soils engineer and were driven to such a depth so as to establish a base fixitive. Well points were drilled around the periphery of the piling and the pump discharges were connected to an outer system which discharges into the Bay. The hole was excavated in two stages. After cutting down approximately ten feet from existing grade, heavy-duty walers were welded to the sheet piling around the periphery of the cofferdam. The contractor purchased steel telescoping struts from another contractor who had performed work for the Bay Area Rapid Transit system. These large telescoping struts were used to brace the cofferdam in both the north-south and east-west directions against the heavy-duty walers. The telescoping struts spanned 110 feet. The excavation then continued down to subgrade with the sheet piling adequately braced in the horizontal direction. A system of small steel tube pilings was driven underneath strategic points along the horizontal struts. Subsequently, the struts were welded to these piles so as to brace the telescoping struts in the vertical plane to prevent buckling. The base slab was formed and placed around the pilings and subsequently the large telescoping struts were removed after a new bracing system was installed between the top of the foundation slab and the walers. The contractor maintained the dewatering system around the clock throughout the first six months of construction as recommended by the soils engineer and an alarm system was installed should one of the pumps fail. However, no failures occurred during the construction.

The volume of concrete contained in the base slab was approximately 3,600 cubic yards. The contractor proposed that this placement be made in three sections. The concept, along with the proposed construction joints, were approved and the contractor successfully made the three described placements. In order to accomplish the large placement of approximately 1,200 cubic yards in one day, the contractor set up two major



concrete conveyor systems in order to rapidly place mass concrete in the base slab. Completion of these three major placements were crucial in the contractor's scheduling.

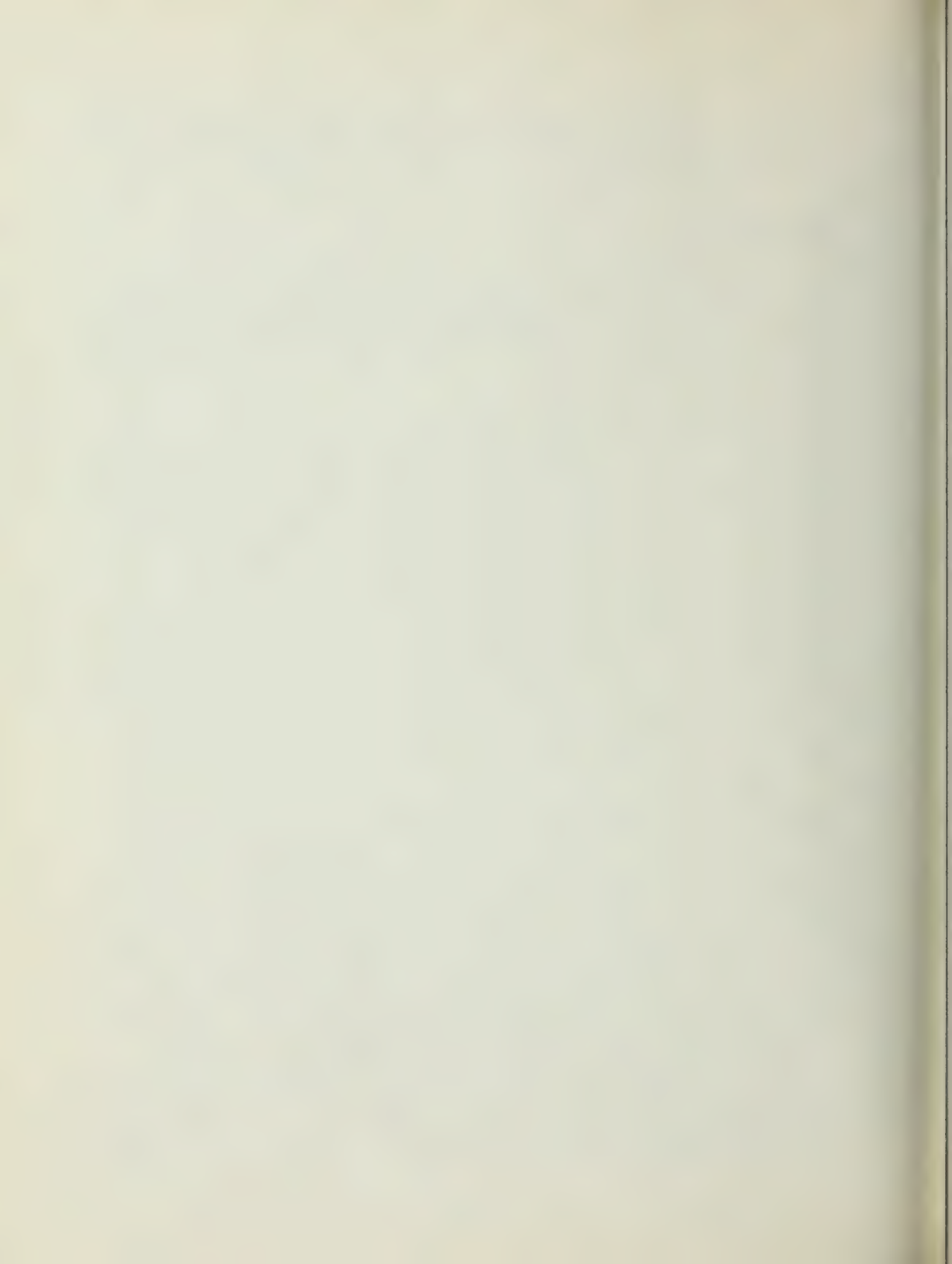
FIELD PROBLEMS

In the course of any major construction project a certain number of field problems are normally encountered. Aided by able and conscientious personnel along with good weather, the contractor fortunately experienced a minimum of major problems.

Outfall - Soils Consolidation

While driving steel sheet piling between Stations 2+20 and 2+60, the contractor experienced extremely low driving resistance. The contractor became concerned and requested that the soils consultant observe the conditions and make recommendations. Subsequently, the soils consultant visited the site and observed that the material encountered in the borings was a loose silty sand similar to that previously observed. The low driving resistance was not inconsistent with the low driving resistance experienced in driving the soil sampler in the original exploration boring. However, because of the possibility of variations in soil conditions and the stated concern of the contractor (who had considerable experience in this type of structure), certain precautions were taken.

Because it was believed that the material was a silty sand and that any settlement that would take place would be rapid, it was recommended that the structure be loaded in increments. Should the initial loading increment indicate that the soils would not support the sheet piling adequately, then traverse tie struts would be required to tie the rows of sheet piling. A lump sum change order was issued to place the surcharge material. Then, extensive measurements were taken to indicate lateral translation, rotation, and vertical settlement of the sheet piles in the area in question. During the laying period readings on the various reference marks were taken frequently each day that the surcharge load was in place. After one week of observations, the maximum settlement in the surcharged area was four inches. The maximum deflection of the sheet piles was 5-1/2 inches. Therefore, it was concluded that the steel sheet



piles would support the pipe and that additional settlement would occur when the pipe ballast rock concrete caps were placed. It was believed that the settlements would be about four inches in the test load area and near the north end of the outfall it would be probably somewhat greater than the estimated six inches stated in the original soils report. Therefore, it was recommended that additional readings of the deflections of the sheet piles be taken as the ballast rock was placed. It was recommended that rocks be placed in at least two lifts with readings taken before and after each lift. Deflections during placement of the ballast pipe and concrete cap were minimal and therefore there was no modification in the alignment nor were any traverse tie rods deemed necessary.

Beach Stairs - Undercutting by Wave Action

The ornamental stairs leading down from the plaza area northward to the beach were observed to be undercut by the wave action and tidal characteristics. These stairs were originally designed as a slab on grade because the original observed condition was that the beach was a "building beach", that is, sand tended to deposit rather than be eroded. However, during the period of construction, the Presidio (which is immediately adjacent to the western boundary of the facility) placed riprap fill and created a groin protruding northerly into the Bay immediately adjacent to the Baker Street dissolved air flotation site. It is believed that the creation of this groin modified the tidal and wave action patterns. As a result, the stairs were temporarily braced and a sheet pile cutoff wall was designed by the City to incorporate mass concrete placement to act as a barrier against the wave action.

CHANGE ORDERS

Throughout the course of the project a total of 14 change orders were required in order to modify the original design, make additions to the contract, and to reimburse the contractor for the unforeseen field problems that were encountered. The total of these change orders resulted in a net increase to the total construction cost of \$31,145, which is approximately 1-1/2 percent of the original contract price.

CHAPTER VI

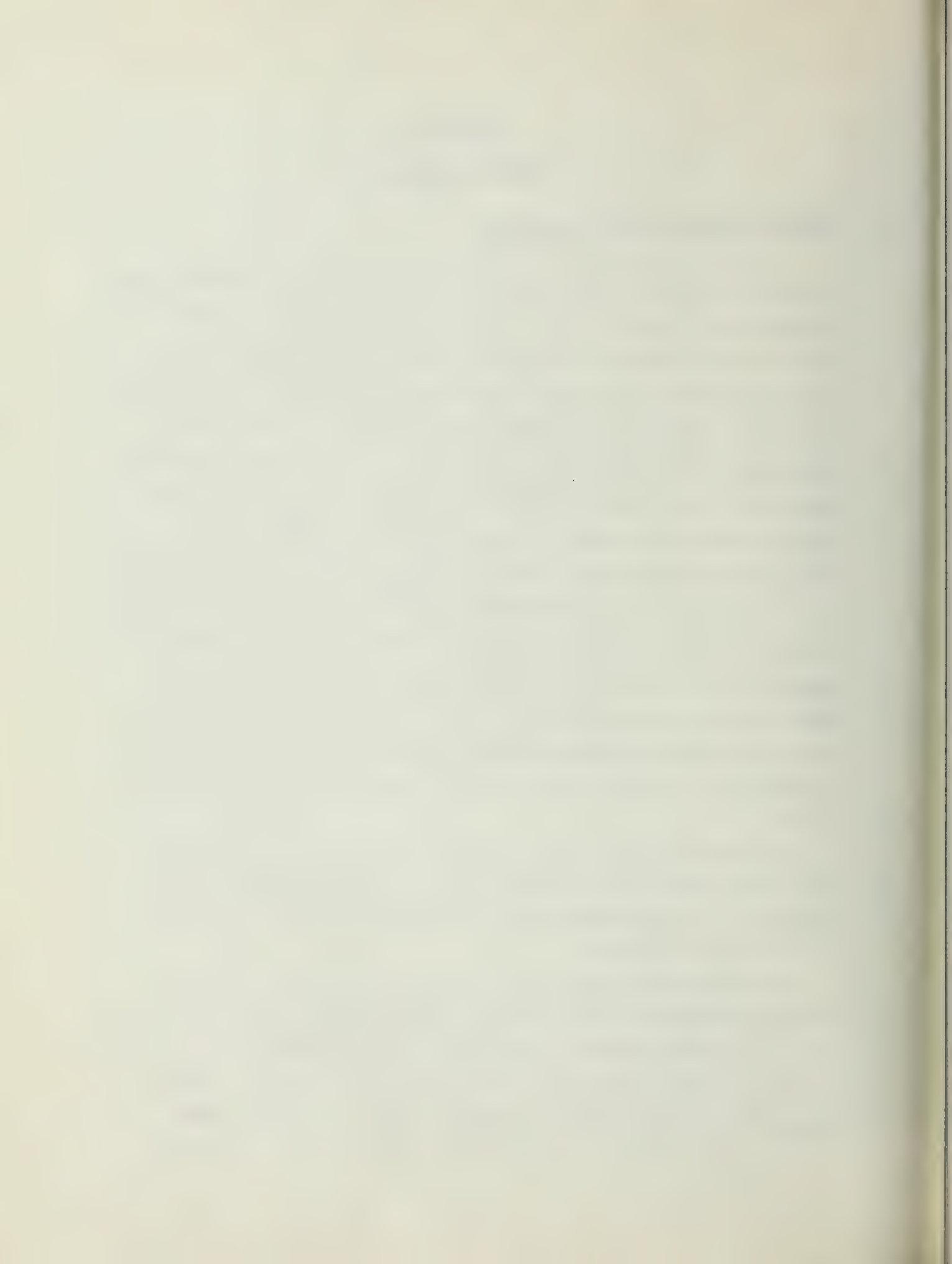
FACILITY OPERATION

NORMAL AUTOMATIC START UP OPERATION

Prior to the occurrence of combined sewer overflow at Baker Street and Marina Boulevard, either the east or the west flotation system is preselected to operate. This is accomplished by means of a 2-way selector switch mounted on the control console. By placing the switch in the "east (west) position" the east (west) plant inlet gate opens first and all the equipment for the east (west) flotation system commences operation as described below. As the rate of flow increases, the east (west) magnetic flow meter senses the flow and sends a signal to the east (west) rate of flow recorder. This recorder sends a signal to the flow adder which sends its output signal to an electronic trip which has an adjustable set point from 0 to 24 mgd and an adjustable dead band of 0 to 100 percent. At an adjustable preset value, the trip energizes a 0 to 60 min adjustable time delay. Upon completion of the time delay the west (east) gate opens and the west (east) flotation system will commence operation as described below. Should the flow drop below the dead band setting before the time delay runs out, the time delay relay will be deenergized and the west (east) gate will not open. The flow must increase again up to the preset values in order to reenergize the time clock.

All electrically operated equipment in both the east and the west plant (except motor operated skim pipes) have hand-off-automatic (HOA) switches. All HOA switches (except for the bypass and the plant inlet gates are console mounted.

When an overflow does occur, the plant start up probe, mounted immediately downstream of the overflow weir at Baker and Marina, sends a signal to a console-mounted level relay. This relay actuates multiple contacts through a relay which directs power to the influent recorders and the ventilation system. As the water level in the inlet system increases, the inlet gate operating level probe, mounted in the plant



inlet structure, sends a signal to another console-mounted level relay. This relay actuates one of two pairs of relays (as chosen by the east-west selector switch) which signals one of the plant inlet gates to open. Flow increases to the present control point, the time clock is energized, and after the time delay (described above), the other plant inlet gate opens.

When any of the following equipment is selected to start and fails to start (within a preset time delay) an alarm is initiated. The respective time delays are shown in the following annunciator system delay relay schedule:

<u>System</u>	<u>Time Delay</u>
(1) Bypass Control Gates	7 min
(2) Plant Inlet Gates	10 min
(3) Bar Screens	3 min
(4) Screening Conveyor	3 min
(5) Sodium Hypochlorite Feed Pumps	3 min
(6) Recycle Pumps	3 min
(7) Air Compressors (pressure drop)	3 min
(8) Screw Conveyors	3 min
(9) Sludge Collectors (two drive units for both east and west)	3 min
(10) Solids Handling Pump	3 min
(11) Ventilation System	3 min
(12) Hydraulic Oil Power Unit	(Controlled by Pressure Switches)

The annunciator consists of a set of light modules and a horn mounted on the control console. During normal operation the light modules glow dimly and the horn remains silent. When a failure occurs for one of the aforementioned items of equipment, the corresponding light module flashes brightly and the horn sounds. The horn is silenced by pressing the *reset* button on the console, and the light remains constantly bright. When the malfunction has been corrected, the light returns to its normal dim light.

As soon as the east (west) magnetic influent flow meter senses flow, both the east (west) mechanically cleaned bar screen and screening conveyor commence operation due to the energizing of contacts interlocked with the flow signal. As the flow passes through the mechanically cleaned bar screens the coarse solids (one inch and larger) are automatically raked, deposited on the belt conveyor, and transported to the storage hopper for ultimate disposal by hauling. When the east (west) system has reached a preset flow value, the west (east) system is placed in operation and the sensing of flow by the west (east) magnetic flow meter causes the west (east) bar screen to commence operation. The bar screens and the conveyor have HOA switches mounted on the control console.

The influent to each flotation system passes through a butterfly valve with electronic operator and thence through a magnetic flow meter. Mounted on the magnetic flow meter is an electronic signal converter, which sends a signal (proportional to flow) to each of four console-mounted instruments as follows: (1) flow indicator-recorder, (2) current converter, (3) flow controller, and (4) flow adder. The signal converter also sends a signal to a panel-mounted flow integrator which sums the total volume of overflow for any given treatment cycle.

The current converters amplify the signal for input to the chemical feeding systems. The flow adder sums the flows from both flotation systems and this total flow signal is input to the bypass control gates system and to the circuitry which energizes the second flotation system. Each flow controller can be manually set between 0 to 12 mgd.

After passing through the butterfly valve and the magnetic flow meter, the flow then enters a 36-in. diameter header in which it is chlorinated with sodium hypochlorite and distributed into the flotation cells. The detention time of 25 minutes in the flotation tanks also provides for chlorine contact time.

As the flow enters the flotation cells it is combined with the pressurized recycle flow (approximately 20 percent of the influent at design flow). When the pressure on the recycle flow is reduced, the dissolved air precipitates forming extremely fine bubbles. The combined influent and recycle are dispersed uniformly across the inlet of the

tank, and the bubbles attach themselves to the grease, floatables, and suspended material in the waste stream, thus forming (by means of adhesion and electrokinetic surface phenomena) a complex bubble-particle matrix which is buoyed to the surface. Redwood flights move the float to automatically operated skim pipes and the bottom sludge to screw conveyors. The skim pipes drain by gravity to the sludge sump and the bottom sludge is air-lifted into the sludge sump.

The flotation tank equipment for each flotation unit (consisting of sludge collectors, screw conveyors, recycle pumps, air compressors, and air-lift solenoid valves) is activated when the level in the flotation tank reaches a prescribed level. The level transmitter, mounted in the first flotation compartment, sends a signal, proportional to differential pressure, to the console-mounted level indicator which indicates the depth of water in the tank. The signal from the level transmitter also passes through an electronic trip, mounted in the rear of the control console. This trip has a 0 to 100 percent range, equivalent to water surface elevations in the flotation tanks between - 9.08 and - 0.58 ft. When the water level in the tanks reaches a preset elevation, another relay with multiple contacts energizes the flotation tank equipment.

Each double section of skim pipe is rotated through a suitable linkage by one constant-speed drive unit which allows a skimming cycle to be completed in 3/4 minute. The linkage is adjustable to provide a means of varying the depth of submergence of the pipe lip.

Each drive unit is designed to rotate each double section of skim pipe so that the lip of the pipe is submerged to a maximum depth of two inches below average liquid level on the upstream side and to a maximum depth of one inch on the downstream side on each revolution. At the end of each skimming cycle a single pole contact limit switch will open to stop the drive motor. The interval between skimming cycles of each drive unit is variable by means of a 0- to 30-min adjustable time clock, mounted in the motor control center. The linkage between the drive units and the skim pipes are so designed that by relocating the connecting points of the linkage, the following can be accomplished:

(1) Back skimming eliminated without increasing front skimming to more than maximum submergence.

(2) Front skimming varied from 1/2-in. depth to the maximum two inches.

To flush the floatable material collected in the skim pipe down the pipe to the sludge sump, flushing water is added at the north end of the skim pipe at the end of each skimming cycle. Flushing water is supplied through a normally-closed solenoid valve. At the end of each skimming cycle a limit switch, mounted on each south skimmer drive, energizes the solenoid valve. After a 0- to 60-sec adjustable time delay the solenoid valve closes.

In order to optimize the stability of the bubble-particle matrix and thus increase efficiencies, provision for the addition of inorganic electrolytes and/or organic polyelectrolytes was made at various strategic points throughout the process piping.

The console-mounted current-to-current converter sends a dc signal, linear with flow to two chemical feeding systems.

(1) Sodium Hypochlorination System. The output from the converter is used by the automatic electric input controller mounted on each of the two sodium hypochlorite feed pumps (one for each flotation unit).

(2) Coagulant Feeding System. The output from the converter is also used by the automatic electric input controllers mounted on the two polyelectrolyte pumps (one for each flotation unit), the alum pump, and the caustic pump. By means of a console-mounted, 2-position switch, polyelectrolyte can be fed to each flotator; or, polyelectrolyte can be fed to either flotator, and alum and caustic can be fed to the other one.

By adjusting the 0 to 100 percent adjustable manual override, mounted in a panel on the wall next to each pump, the dose rate for each pump can be varied according to the strength of the particular chemical being fed.

The chemical feed pumps have the following capacities:

- | | |
|------------------|---------------|
| (1) Alum | 10 to 250 gph |
| (2) Caustic Soda | 1 to 100 gph |

- | | |
|-------------------------|--------------|
| (3) Sodium Hypochlorite | 3 to 75 gph |
| (4) Polyelectrolyte | 2 to 110 gph |

All chemical feed pumps have console-mounted HOA switches.

The solids handling pump is controlled by an electronic differential pressure sensing device mounted in the solids sump. As the sludge level in the solids sump rises, the pump starts. As the level increases, the electronic differential pressure sensor sends a signal (proportional to the level in the sump) to the variable speed control panel, mounted in the motor control center, controlling the speed of the solids handling pump through the eddy current type, electromagnetic, clutch drive unit, according to the following conditions:

	<u>Condition 1</u>	<u>Condition 2</u>
Capacity	550 gpm	260 gpm
Total Dynamic Head	120 ft	35 ft
Horsepower	40 hp	40 hp
Speed	1,717 rpm	900 rpm
Maximum Shutoff Head	140 ft	- - -

The output from the pump is metered by means of a magnetic flow meter on the discharge side of the pump. An electronic signal is sent from the magnetic flow meter to a flow indicator and integrator. Both the flow indicator and the flow integrator are field mounted locally in one common panel adjacent to the meter.

The solids handling system operates completely independent of other plant systems and equipment. All sludge and floatables are pumped through an 1,800-ft force main to the Marina Street Pump Station, where it is pumped to the North Point Treatment Plant.

HIGH LEVEL CONTROL OPERATION

The flow adder sends a signal to the electronic trip (described above under normal automatic operation). When the signal to the trip exceeds the preset level, the same signal is sent to console-mounted gate flow controller. This flow controller sends a signal to the console-mounted control valve positioners. These positioners are used

to position the gates by comparing gate position from the output signal of the gate opening feedback indicator-transmitter, which senses mechanical gate motion. Operating relays in the positioner direct the operation of the solenoid-operated, directional control valves in the hydraulic system. When the total plant flow (as measured by the flow adder) equals or exceeds the preset point on the gate flow controller, the gates open in parallel to bypass excess flow. When the total plant flow is less than the preset point, the gates will move toward the closed position or remain closed, if already closed.

EMERGENCY LEVEL CONTROL OPERATION

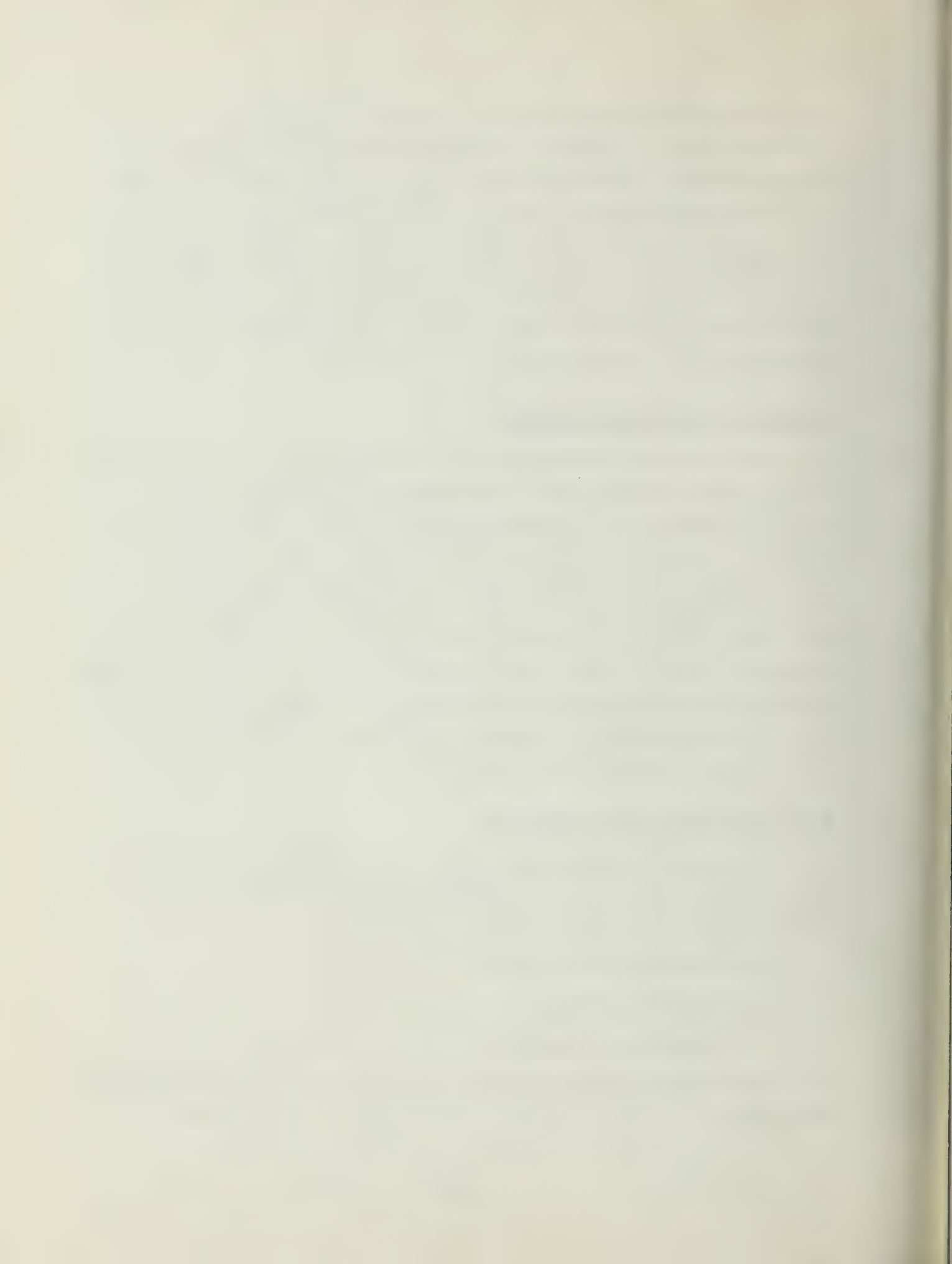
When the total influent storm flow exceeds the hydraulic capacity of the facility, the bypass gates are actuated by an emergency actuating system. Emergency high level and emergency low level cutout probes will sense the water level in the overflow structure at Baker and Marina. When the water level reaches a preset and adjustable level, a signal is sent to a console-mounted level relay. The level relay connects a control relay into the gate control circuit, and causes both gates to open, in parallel, at 12 in./min. When the water level in the overflow structure at Baker and Marina falls below the emergency low level, a signal is sent to the console-mounted level relay which will again allow the gate flow control signal to operate the bypass gates.

ELECTRICAL POWER FAILURE OPERATION

In the event of an electrical power failure, the 15-kw diesel engine driven standby electric plant automatically comes on line. This standby generator will supply power to the following:

- (1) Emergency lighting panel.
- (2) Ventilation system.
- (3) Hydraulic oil power unit.

Also, the bypass control gates will open in the event of an electrical power failure.



AUTOMATIC SHUT DOWN SEQUENCE

As rainfall abates and runoff subsides, the combined sewage flow to the plant will decrease. Eventually the water surface in the plant inlet structure will drop below the required operating level. This is due to the sewage flowing into the dry-weather system (the 21-in. diameter sewer upstream of the overflow weir at Baker and Marina which flows easterly to the Marina Pump Station). If no more storm water enters the collection system, the waste in the flotation tanks and in the inlet system drain to a final elevation of - 6.60 (the elevation of the overflow weir at Baker and Marina) through the 21-in. sewer.

When the level in the flotation tanks falls below a preset elevation, electronic trips cause the following items of equipment to shut down:

- (1) Recycle pumps.
- (2) Air compressors.
- (3) Sludge collectors.
- (4) Solenoid valves for air lift pumps.
- (5) Screw conveyors.

When the water level in the plant inlet structure falls below the inlet gates closure probe, a signal directs both plant inlet gates to close. After the gates are closed, no flow passes through the magnetic flow meters, and the chemical feed pumps shut off.

When the level of the water upstream of the overflow weir at Baker and Marina falls below the plant shut down probe, located upstream of the weir and immediately ahead of the entrance to the 21-in. diameter (dry-weather system) sewer, a relay deenergizes and causes the following items of equipment to shut down:

- (1) Bar screens.
- (2) Screenings conveyor.
- (3) Ventilation system.
- (4) Flow recorder chart drives.

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